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# Sedimentation near the mouth of Mullet Creek, Lake Illawarra

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## Abstract

This study looks at sedimentation at the mouth of a small coastal delta. Its main aim is to describe and account for the decline in environmental quality at the stream's outlet by examining the delta's growth and form, sediment distribution and channel geometry, thereby gaining an understanding of processes occurring throughout the system with the aid of theoretical models. The result is an assessment of the most suitable means of overcoming the practical problem of sedimentation. Results showed that the cause of sedimentation was largely due to the introduction of a man-made channel, which has re—directed stream and sediment discharge away from the old stream mouth and into a shallow bay. Stream erosion and siltation have occurred as a result of these changes. Nevertheless, the artificial channel should remain open, as overbank flow during high discharges is common along the creek, and further restriction downstream would initiate a back—log of floodwaters upstream, causing extensive flooding to residential, commercial, industrial and rural properties. Instead, a proposal to dredge sediment accumulated in the bay and along the stream channel (to increase channel capacity) was put forward, noting that stricter controls and policing of land development in the creek's catchment be immediately implemented. The study therefore demonstrated that a sound knowledge of channel form and dimensions, of flood behaviour, and of depositional patterns is essential if a deterioration of environmental quality is to be avoided. This knowledge needed to be based on and linked to the general theory of delta development as well as direct field observation.


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# SEDIMENTATION NEAR THE MOUTH OF MULLET CREEK:
# LAKE ILLAWARRA.

by

B.T. HORAN

A thesis submitted in partial fulfilment of the requirements for the Honours Degree of Bachelor of Arts in the Department of Geography, The University of Wollongong, 1981.

# ABSTRACT

This study looks at sedimentation at the mouth of a small coastal delta. Its main aim is to describe and account for the decline in environmental quality at the stream's outlet by examining the delta's growth and form, sediment distribution and channel geometry, thereby gaining an understanding of processes occurring throughout the system with the aid of theoretical models. The result is an assessment of the most suitable means of overcoming the practical problem of sedimentation.

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The study therefore demonstrated that a sound knowledge of channel form and dimensions, of flood behaviour, and of depositional patterns is essential if a deterioration of environmental quality is to be avoided. This knowledge needed to be based on and linked to the general theory of delta development as well as direct field observation.

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> "Come unto me all you who are weary and burdened, and I will give you rest. Take my yoke upon you and learn from me, for I am gentle and humble, and you will find rest for your souls. For my yoke is easy and my burden is light."
>
> \- Jesus Christ (Matthew 11:28-30, N.I.V.)

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# CHAPTER ONE

# THE PROBLEM

## 1.1 Introduction

This is essentially a study in applied geography which seeks to apply, rather than to test theoretical constructs. The aim has been to describe and account for sedimentation near the mouth of a small coastal delta with a view to advising on the most suitable means of overcoming what has for some time been seen as a serious decline in environmental quality. Field research into this problem consisted of a six month study of delta growth and form, sediments, and the morphology of bars and channels; prolonged drought precluded direct measurements of flood regime. However, this work was not just empirical observation, for it was guided by generalisations and models called from the considerable literature dealing with deltas. Although the study is thus essentially of an applied type, the results do point to the need for some modification of the models used.

## 1.2 General Problem

### 1.2.1 The Value of Coastal Lagoons

Mullet Creek Delta debouches into the shallow waters of Lake Illawarra. Like most other coastal lakes, Lake Illawarra is used intensively by the local population. It is a lake surrounded by a rapidly growing urban-industrial city and can be regarded as a valuable resource to the region. Studies of tourism have shown that the most significant user of the lake originates within the Illawarra region and even more specifically within the immediate heavily populated areas within a few miles of the lakefront (Robinson, 1971). Use of the lake is considerable with a growing number of people pursuing both recreational and economic purposes; recreational activities are carried on side by side with professional prawning and fishing. As the region expands there will be an even greater demand for Lake Illawarra to be used for these purposes. But, if the lake's potential is to be available for future generations, effective management will be needed, for landuse pressures have already led to a decline of environmental quality. The main problem to be faced is not the once much-published quality of water but is rather that of infilling with sediment (Young, 1976).

### 1.2.2 Infilling of Coastal Lagoons

Infilling is a significant problem in many coastal lagoons in New South Wales. Roy et.al (1980) suggest that embayments along the southeastern Australian coast show varying degrees of infilling with both 'fluvial' and 'marine' sediments. A large degree of this infilling is believed to have occurred in mid-Holocene times where rapid marine sand accumulation has caused the formation of coastal sand barriers and estuaries that progressively infilled with fluvial/ estuarine deposits. Recent intensification of infilling lagoons is also evident, for Young and Nanson (1979) show that a major upsurge in sediment yield was caused by the clearing of vegetation from catchment areas. Narira delta in Wallaga Lake, for example, has experienced nearly a six to eight fold increase in the rate of delta growth subsequent to clearing of the Narira catchment in the midnineteenth century. Over a 28 year period from 1944 to 1972 the delta has added 258 $m^2$. of sediment to Wallaga Lake at an average rate of 9.2 $m^2$. per year.

Young (1976) also notes that the clearing of the forests, when 'the laying bare of hillslopes led to serious sheet erosion and the increased runoff led to gully development in alluvial fills along drainage lines', led to a great increase in sedimentation in Lake Illawarra, especially at the mouth of Macquarie Rivulet. He noted that climatic change could also have triggered periods of deposition and erosion in the Lake Illawarra Catchment, and that infilling of the lake since European Settlement could largely be attributed to changes in landuse, in association with periods of heavy flooding.

Coastal lagoons of the 'barrier estuary' type, like Wallaga Lake and Lake Illawarra, can be seen to be slowly infilling, due mainly to the buildup of extensive, subaqueous 'mud basin' deposits from estuarine and fluvial sources, together with the growth of tidal deltaic sand bodies, that form at the inner ends of inlet channels, and also the expansion of tributary stream deltas (Roy et.al., 1980). This infilling continues until flood plain deposits confine the tidal prism to the river channel (Fig. 1.1).

The surface area of Lake Illawarra has decreased by about 17% from around 40 to 33 $km^2$., but 90% of the volume of the original lake basin has already been infilled with sediment (Young, 1976). The need for careful planning of the lake is obvious, and without it siltation will probably accelerate, until Lake Illawarra ultimately resembles the 'completely infilled barrier estuary' illustrated in Roy et. al.'s (1980) model.

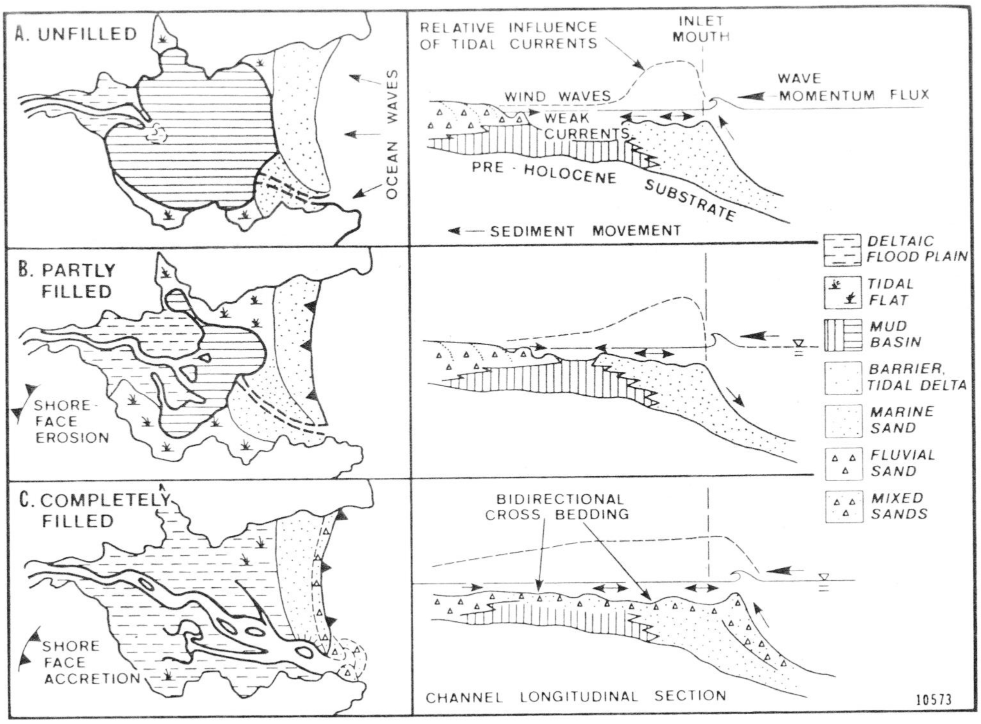


Fig. 1.1: Changes in geometry, process regime and lithofacies with progressive infilling of an idealised 'barrier estuary' (after Roy et.al. (1980)).

## 1.3 The Specific Problem of Mullet Creek

The effects of siltation on Lake Illawarra can be seen by examining Mullet Creek Delta. Sediment discharged by the creek has formed a three km. long cuspate/lobate delta. In the early 1940's an anti-tank ditch was dug connecting the lower reaches of Mullet Creek to Lake Illawarra (Fig. 1.2c). This ditch (known as the Tank Trap) has subsequently redirected sediment discharge away from the delta mouth and formed a secondary deltaic deposit of considerable size at the mouth of the new channel. As a consequence, the bay into which the new channel now debouches (Koong Burry Bay) has slowly shallowed as subaerial deltaic features have developed (Plate 1). The rapid reduction in water depth of the bay has initiated mounting concern by both community and local government bodies. In addition, the Mullet Creek channel is slowly silting up as normal flow is now concentrated through the Tank Trap, with flushing of the old channel occurring only in periods of high flow. Solutions need to be found therefore to the problems of siltation within the stream channel and in Koong Burry Bay. The solutions suggested here are derived from field evidence and by applying general concepts and models.

## 1.4 Location and Setting

Lake Illawarra is an almost completely enclosed coastal lake located about 75 km. south of Sydney. Formed in the lower part of two stream valleys behind a coastal barrier, the lake has a length of 8 km. north to south and a width of 4 km.; with a perimeter of 30 km. and an area of 33 km.$^2$. The lake is situated at the southern end of a narrow coastal plain which is backed by foothills of the

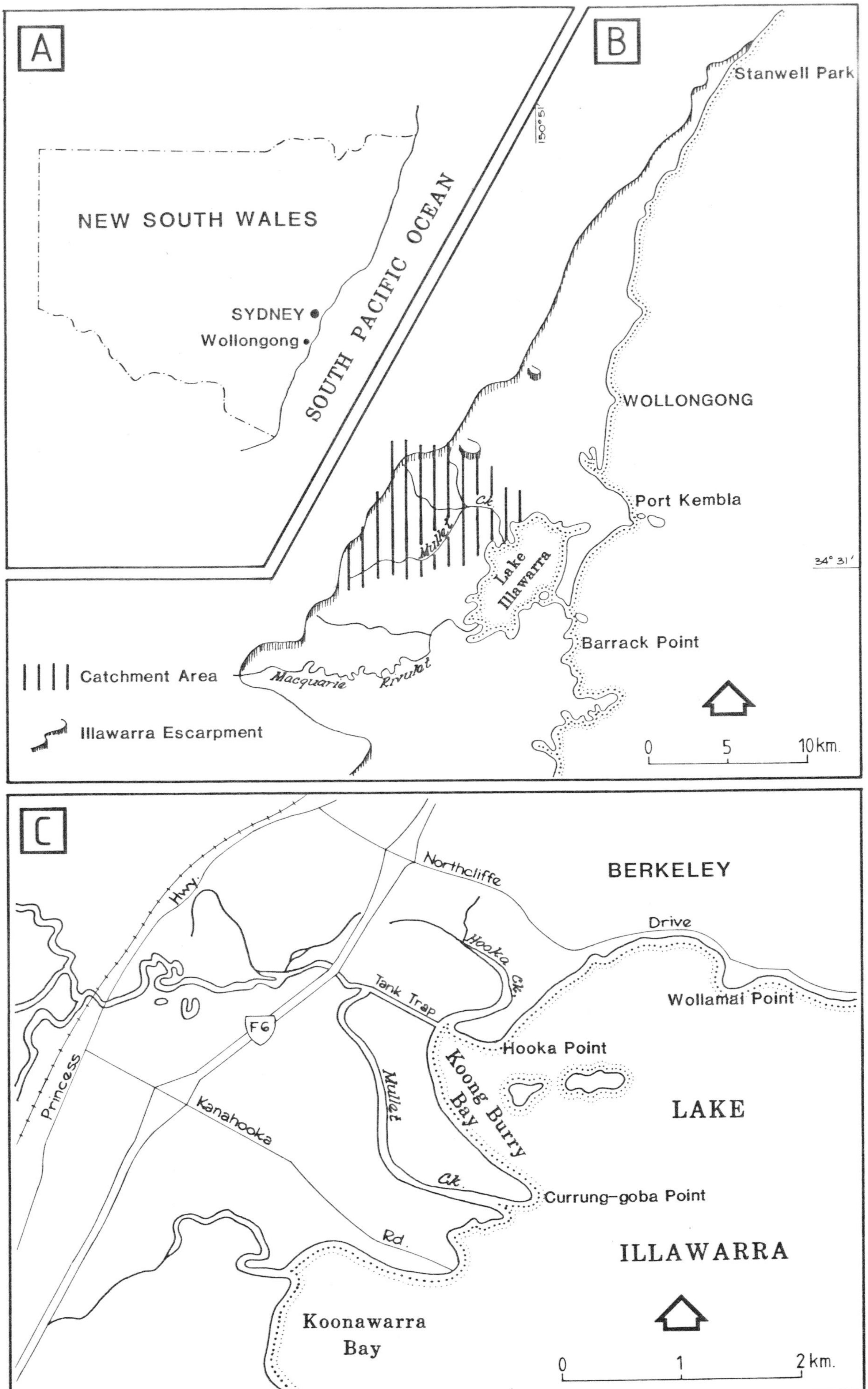


FIGURE 1.2: Mullet Creek Study Area

Plate 1. An aerial view of infilling in Koong Burry Bay at the Tank Trap mouth (12/6/1981).

Illawarra escarpment rising to a maximum height of 600 m. (Fig. 1.2B).

Mullet Creek flows off the foothills of the Illawarra escarpment and travels east until it enters the northwestern corner of Lake Illawarra near Berkeley (Plate 2). The creek drains a catchment area of 67 $km.^2$ comprising Tertiary basalts, Wianamatta shales, Narrabeen Group shales, Illawarra Coal Measures, and Gerringong Volcanics.

Unconsolidated sand, silt and clay of fluvial origin fill the lower valley of Mullet Creek. These sediments have formed low-lying plains and deltaic deposits which have been reworked within the lake to form extensive beach ridges. Finer sediment has been carried in suspension into the lake, and deposited under low energy conditions on the lake bottom.

On the eastern side of the lake a coastal sand barrier links the headlands of Port Kembla in the north and Barrack Point in the south (Fig. 1.2B). At the southern end of the barrier a shallow entrance channel intermittently links the lake with the sea. A tidal delta has formed on the western end of the channel, where sand is transported into the lake by tidal action (Roy and Peat, 1973).

## 1.5 The Approach to the Problem

In the following chapters the study will aim to offer a solution to the problem of siltation around Mullet Creek Delta. The general approach will include:

(i) an application of general models of delta development in an attempt to describe the mechanisms and processes operating on Mullet Creek Delta;

(ii) a description of delta growth and form including the methods

Plate 2. Mullet Creek enters the northwestern corner of Lake Illawarra near Berkeley - scene looking southwest (12/6/1981).

used, its present-day form and its pattern of change over the years;

(iii) a sedimentary analysis of offshore bars and deltaic channels which involves a description of the distribution of sediments and deductions from these distributions in relation to processes operating on the delta and limitations on rehabilitation;

(iv) an examination of catchment characteristics including downstream trends, discharge, and modification of the catchment, and an analysis of deltaic channel features and their implications to future management of the delta;

(v) a discussion of alternate management proposals for the delta and an evaluation of the effects of such proposals; and

(vi) an analysis of the specifics of this site and the implications for delta development in general.

# CHAPTER TWO

## THEORETICAL FRAMEWORK AND REGIONAL SETTING

Several reports on Lake Illawarra have studied barrier stratigraphy, and the processes influencing tidal deltas and their impact on lake infilling (Illawarra Lake, 1976; Roy and Peat, 1973; Robinson, 1971), but little information is available on the mechanisms and processes operating on the small stream deltas on the lake's western shore and their influence on lake sedimentation. This study of the Mullet Creek Delta has had to break new ground, and in doing so it has not only included empirical observation but followed guidelines offered by general models of delta development. The literature on deltas is voluminous and only those papers which had a direct bearing on this study are listed here.

Wright (1978: p.5) defines deltas as 'coastal accumulations, both subaqueous and subaerial, of river-derived sediments adjacent to, or in close proximity to, the source stream, including the deposits that have been secondly molded by various marine agents, such as waves, currents or tides'. In his paper Wright gives a general discussion of deltas which includes a summary of concepts and conclusions contained in the work of Coleman and Wright (1975), but also introduces other delta components, such as the subaqueous and subaerial delta and the active and abandoned delta (Fig. 2.1). In addition he tends to elaborate more on river-mouth processes, concentrating on the aspects of turbulent jets and the effects of bottom friction, and hypopycnal effluents and the role of bouyance, giving an example of the Mississippi River mouth morphodynamic model.

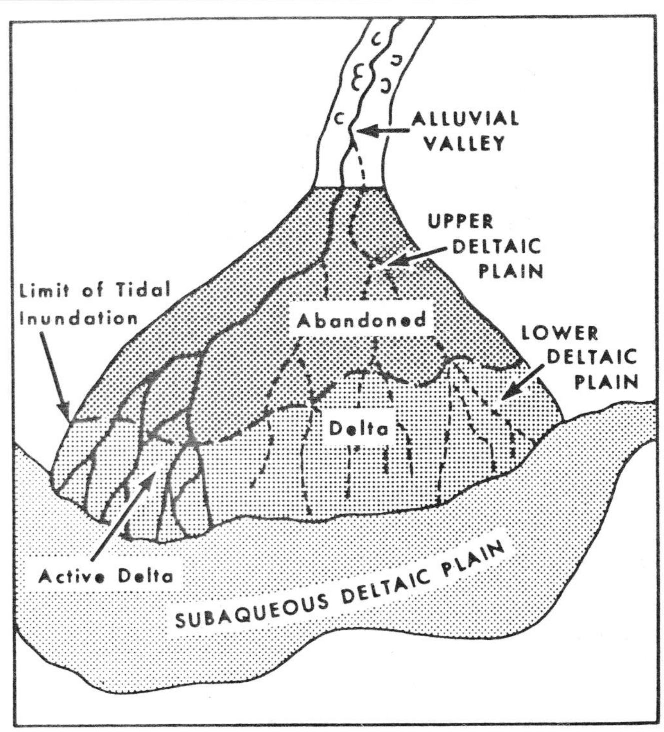


Fig. 2.1: Components of a Deltaic Plain (after Coleman, 1976).

He also discusses deltaic sediments and sedimentary structures which include the prodelta, delta front, channels and distributary margins, interdistributary bays and flats, beach and dune deposits and marshes and swamps. As is shown in the following chapters the description of these additional delta components were of particular importance in understanding the processes and delta characteristics of Mullet Creek Delta.

Further insight to delta processes on Mullet Creek comes from the work of Bates (1953), who looked at the transportation and deposition of river sediment into different receiving basin environments. He referred to outflows from river mouths having negligible density contrasts (for example, freshwater streams entering freshwater lakes) as homopycnal (i.e., having equal density), compared to hypopycnal outflows, which are characterised by bouyant river water issuing into denser basin water; and thirdly hyperpycnal outflows, in which the issuing water is denser than, and plunges beneath, the basin water. Modifying effects of winds, waves, and tides on deltaic deposits were discussed briefly.

Roy et.al. (1980) illustrated that coastal embayments along the southeastern Australian coast showed varying degrees of infilling with 'fluvial' and 'marine' sediments. They recognised three primary types of Holocene embayment fill to exist, 'open ocean', 'barrier estuary' and 'drowned river valley'. An evolutionary model was proposed in each case to account for their various stages of development. They predict that with extreme or prolonged wave erosion, barriers may be destroyed and estuarine deposits reworked to produce mixed 'fluvial'/'marine' sediments; with similar polygenetic sediments being produced when an estuary completely infills and river sand is supplied to the coast. The latter of these models could be applied to Lake Illawarra if sedimentation, caused by urban expansion and mismanagement of rural land, continues to increase in the future.

The most useful model for this study was that of Coleman and Wright (1975). These authors note that deltaic depositional facies result from interacting dynamic processes which modify and disperse transported riverine sediment. Furthermore, these processes, which vary in both intensity and frequency, were found to control the eventual framework of a delta.

The river system within which these processes operate has been broken up into four main components, namely: the drainage basin, alluvial valley, deltaic plain, and receiving basin. By definition: the drainage basin functions as a source of water and sediment, where basin processes effect the sediment-water supply and the initial composition and size of the sedimentary load. Processes which operate within the drainage basin are climate, relief, water, discharge regime and sediment yield; the alluvial valley is 'essentially a conduit in which the river flows over and through its own deposits' (Coleman and Wright, 1975: p.100). Sediments sometimes accumulate within the alluvial valley and an alteration of sediment size and composition can occur due to sediment trading. Basin tectonics, climatic influences and changes in sea level also have an impact on the alluvial valley; the deltaic plain forms where the river ceases to function primarily as a transporting agent and becomes a dispersal system. Its formation results from the interaction between riverine and marine processes. Coleman and Wright note that the morphology and geometry of the delta reflect hydrologic regime, sediment load, geologic structure and tectonic stability, climate, tides, winds, waves, water density contrasts, coastal currents, and the innumerable spatiotemporal interactions of all these factors; the receiving basin is a body of water into which a stream debouches, e.g., ocean, gulf, inland sea, estuary or lake. The various processes that are active near the delta coast are crucial to the shaping of the delta and just as important to the development of a delta as is the river.

In summary, it can be noted that processes and other factors, occurring within the components of a river system, exert significant control on the geometry, genesis, and distribution of deltaic facies (Fig. 2.2). Furthermore, individual processes normally result in specific responses in a particular delta, for example the climatic regime in the delta results in determing the type of in situ deposits; high or low wave energy may reflect sand bodies that show either fluvial or marine character; the presence or absence of littoral currents may cause delta sand bodies to orient themselves parallel to the depositional strike or at high angles to the shoreline; and high or low tides result in either sand-filled or clay-filled estuaries.

When studying Mullet Creek Delta, therefore, the characteristic processes operating in the drainage basin, alluvial valley, deltaic plain and receiving basin needed to be defined so that the corresponding processes and responses outlined in the literature could be investigated. A description of local conditions and a summary of applied theoretical concepts are listed below.

(i) Climate

Coleman and Wright (1975) note that climate affects runoff, morphology and sediment-water discharge, and thus exerts a considerable effect on delta development. The Mullet Creek system has a temperate

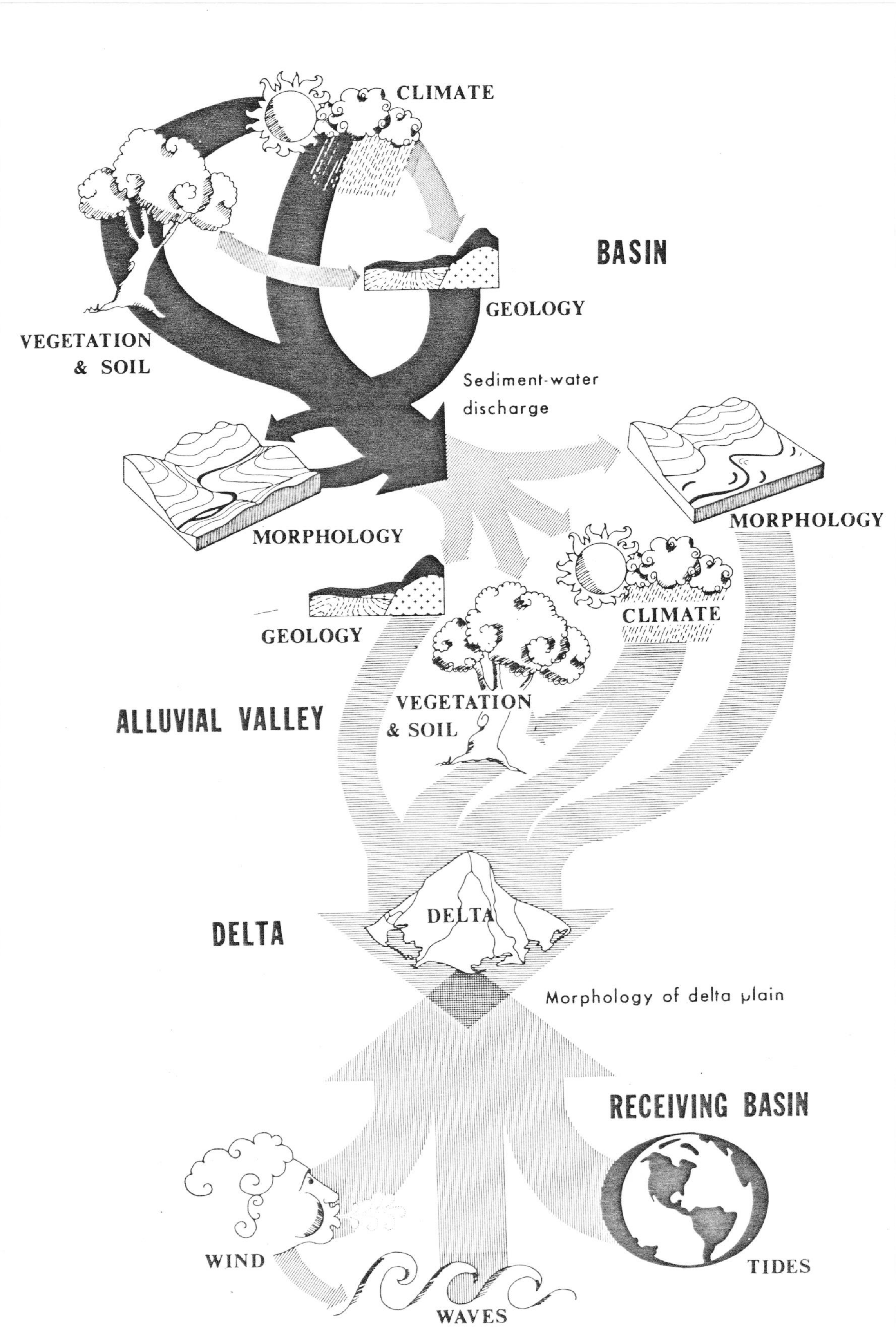


Fig. 2.2: Diagram of Process Interactions in a River System.

maritime climate with average monthly temperatures ranging from 22° in January to 13° in July. The average annual rainfall in the receiving basin is 1100 mm. with 1300 mm. in the main alluvial valley, increasing to 1600 mm. in the headwaters due to a marked orographic effect near the crest of the escarpment (Fig. 2.3). Nanson and Young (1981: p.241) point out that 'average annual runoff increases from ≃ 177 mm. on the coastal lowland to ≃ 1000 mm. near the escarpment crest [A.R.M. Young, 1978]. Rain generally comes from cyclonic storms over a period of a few days during which intensities on the scarp have reached nearly 600 mm. in 24 hr. At Mt. Keira, for example, 24 hr. falls increase from 240 mm. at a recurrence interval of 2 yr., 300 mm. at 5 yr. and 500 mm. at 25 yr.'

(ii) Relief in Drainage Basin

Coleman and Wright also argue that relief reflects and controls such factors as vegetation cover, drainage density and hydraulic regime, with a high sediment yield being related to high relief. Relief over most of the Mullet Creek catchment is relatively low and the majority of tributary streams flow off the undulating foothills of the Illawarra Escarpment. However the steep slopes of the 600 m. escarpment in the headwaters could induce an increase in runoff and sediment yield (Fig. 2.3). Unfortunately no data are available.

(iii) Water Discharge Regime

According to Coleman and Wright the higher the annual discharge, the larger the annual sediment load. In addition, temporal discharge distributions and variations were seen to exert a great influence on valley and delta morphology than do absolute discharge magnitudes and central tendencies. Total discharge in Mullet Creek

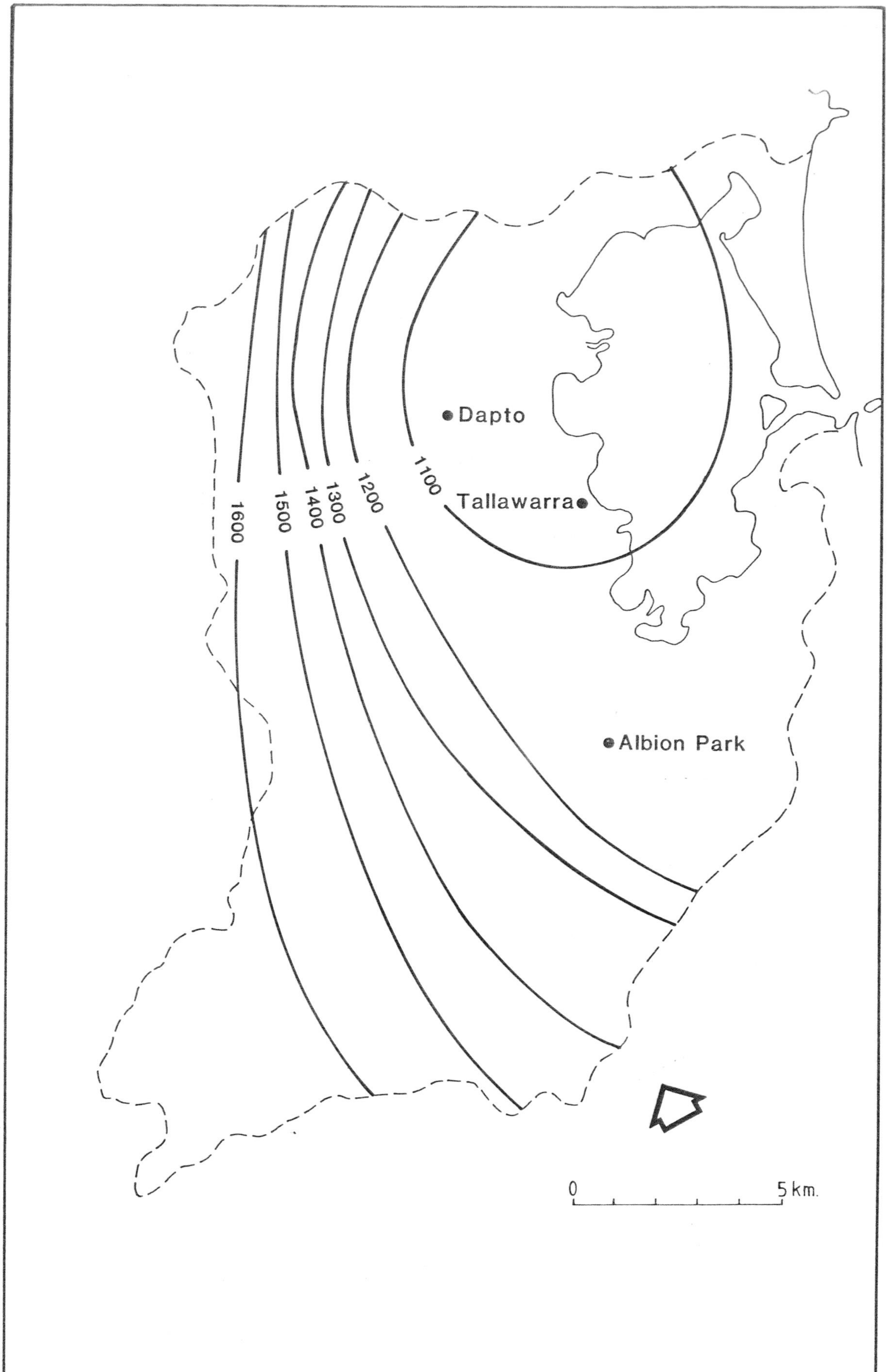


FIGURE 2.3: Annual Average Rainfall (mm) for Lake Illawarra's Catchment Area
(Source: Figure 4.1, Illawarra Lake Study, 1976 : page 41)

increases downstream with discharge variations being fairly slight, however floods that do occur are sometimes extremely flashy; with an estimated annual flood of 13,000 megalitres through the mouth of Mullet Creek (Illawarra Lake, 1976). During these flood conditions discharge runs over onto the low-lying floodplains, as there is a considerable reduction in channel capacity downstream. Consequently sediment tends to accumulate on the floodplain instead of being carried into the lake. Generally, however, annual flow is more or less evenly distributed throughout the year, with stable channels occurring and a meandering type of stream resulting.

Water discharge is also important in affecting the rate and pattern of delta growth, in that the ability of a stream to overwhelm the receiving basin processes depends significantly upon the volume and intensity of the outflow.

(iv) Sediment Yield

No studies have been made of sediment yields in this catchment, and unfortunately the drought conditions throughout the duration of this piece of research gave no scope for the collection of meaningful figures. Observations of bed material indicate that a mixed load of sand and silt is carried by the creek.

Present day delta deposits on Mullet Creek include a 600 m. subaqueous extension from the old delta mouth and a 0.35 km. x 0.35 km. deposit off the Tank Trap (Young and Reffel, 1981). These bars consist of sands and sandy muds which could have originated from the creek's coarse bedload or from the predominantly fine-grained channel walls. In addition to this, there is evidence of extensive subaqueous prodelta platforms of fine-grained unstable clays.

(v) River-Mouth Processes

Coleman and Wright (1975: p.107) believe that hydraulic conditions present at the river mouth are responsible for controlling the sand distributions and forming distinctive types of bars; where 'the relationships between inertial, bouyant and frictional forces strongly controls effluent spreading patterns and affects the geometry of the distributary-mouth bar deposits'.

The authors have identified five major types of river-mouth bars, namely: radial; lunate; middle-ground or bifurcating type; subaqueous jettied type and linear tidal ridges (Fig. 6, Coleman and Wright, 1975). Both the Mullet Creek subaqueous delta and the 'Tank Trap Delta' resemble the radial type of bar. This bar type is one which shows a great deal of spreading and whose sands have disseminated a long distance laterally from the river mouth; a bar that is common at river mouths where frictional forces are dominant, with bouyancy playing a minor role, except during low river stage - and being characterised by a prominant bulge in the subaqueous contours (Fig. 2.4).

Furthermore, Coleman and Wright identified three major types of delta channels at individual river mouths - consisting of: seaward-bifurcating channels; rejoining channels; and single channels. The single channel is said to normally display a bell shape, and lunate bars or tidal ridges are common. Mullet Creek Delta mouth has a single channel and does display a bell shape but lunate bars and tidal ridges are not evident. Likewise, high wave action, high tide ranges, and steep offshore slopes are normally associated with this type of distributary pattern, and long, linear sand bodies are common but this is not the case with Mullet Creek Delta mouth.

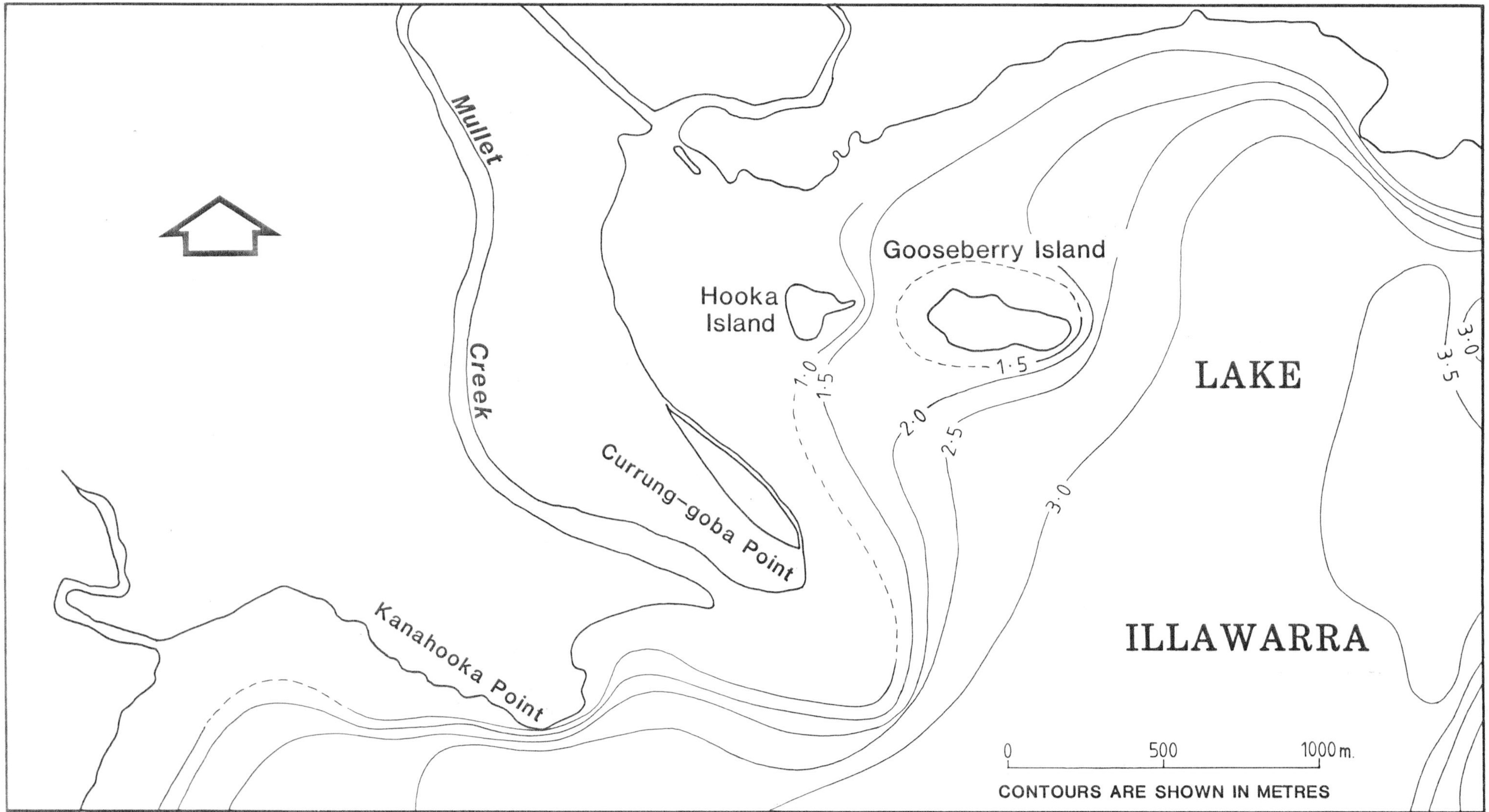


FIGURE 2.4: Lake Bathymetry off Mullet Creek (after Roy & Peat, 1973)

(vi) Wave Power

Wave power can have a significant impact on coastline development due to the interaction of sediment transporting processes at the mouth of a stream and the wave regime in the receiving basin. Coleman and Wright (1975: p.109) note that 'the resulting geometry of the sand bodies depends not only on the magnitude and distribution of wave forces but also on the ability of the river to supply sediments'. A number of different deltaic sand body configurations are consequently formed, ranging from those which reflect complete dominance by waves in redistributing sediments, to those produced solely by the debouchement of the river, without interference from wave action. Due to gentle offshore gradients formed off the mouth of the Tank Trap and Mullet Creek relatively low wave energy is present, with waves of up to 35 cms. being dissipated over a broad area (Illawarra Lake, 1976). The sand bodies produced are therefore essentially products of riverine processes, being characterised by the formation at relatively high angles to the shoreline trend.

(vii) Tidal Processes

Tides can account for a large amount of sediment-transporting energy especially in the lower stream course where reversals over a tidal cycle occur. In high-tidal-range regions velocities may fluctuate constantly in the distributary channels due to the water level fluctuating daily. As a result sediment being carried in suspension and as bedload have the potential of being deposited during lower current velocities causing sandy shoals to form. Velocity in low-tidal-range environments, however, is normally great enough to keep most of the sediment supplied to it in suspension or moving along the bottom as bedform migration. Shoals are therefore uncommon in these latter environments as little sediment accumulates in the channel. Tidal influence in Lake Illawarra is very low with a tide range of 3.3 cms. or in the order of 2-3% of the outside ocean (Illawarra Lake, 1976). The influence tides have on Mullet Creek Delta are therefore very minimal which indicates that water level fluctuations would not greatly affect channel velocities transporting sediment to the lake.

(viii) Wind Systems

Coleman and Wright (1975: p.111) explain that 'the wind is responsible for aeolian transport of sediment over the subaerial delta plain, the generation of wind waves, the generation of coastal currents, and the set up and set down of the water surface along the coast'. Wind stress applied to nearshore waters can create local wind waves and produce nearshore coastal currents. The former is responsible for reworking sediments and concentrating small strandline sand bodies, and the latter can cause piling up and lowering of water along the coastline (set up and set down).

Near Mullet Creek Delta the effect of local wind waves are not very significant in moving sediment. There are, however, strong onshore and offshore winds throughout the year (up to 45 km/hr for NE winds and 55 km/hr for S winds in summer, and W and SW winds in winter having velocities ranging up to 45 and 50 km/hr respectively - Illawarra Lake Study, 1976) which could influence water level set-up and set-down. This in turn could be a minor agent for sediment transport.

(ix) Currents

Eliot et.al. (1976) speculate that the major currents operative along the northern shoreline of Lake Illawarra are those associated with stream flow from within the Tank Trap, wind drift currents in the vicinity of Berkeley, and wind drift and wave driven currents from Wollamai Point to Griffins Bay (Fig. 4.4, Illawarra Lake, 1976). Eliot et.al.(1976) also assume current velocities may be high during floods when the Tank Trap discharge is greatest. He points out, however, that velocities may rapidly decline when the stream debouches into the lake, causing deposition of coarse sediment at the Tank Trap mouth and reworking of finer sediment eastwards along the Berkeley Shoreline. However nearshore sampling by Young and Reffel (1981) reveals no apparent northward movement of Tank Trap deltaic sediments which was supposedly threatening to inundate facilities at Berkeley Boat Harbour (the western side of Wollamai Point). Field observations from their study also show no further eastward sediment movement to Griffins Bay.

(x) Shelf-Slope

The subaqueous shelf was found by Coleman and Wright (1975) to control wave power that reaches the shore, due to the frictional effect it has on incoming deepwater waves. As noted above, the shelf surrounding Mullet Creek Delta is fairly broad, having a very gentle slope of 1:30 (Roy and Peat, 1973), and this tends to dissipate incoming waves. It was also noted by Coleman and Wright (1975) that the shelf has a major role in determining the pattern of delta switching over geologically longer periods of time. The authors defined three types of delta migration patterns, namely: lobe switching, channel switching and channel extension. This last type occurs where two or more distributaries break off at a nearly common point at the head of the delta and continue unbranched to the river mouth. As a result, one of the distributaries will carry the majority of the sediment-water discharge at any given time. In a sense this form of delta migration could be applied to Mullet Creek Delta, although shelf-slope is not the contributing factor. The Tank Trap can be considered as an artificial, or man-made, analogue of natural delta switching (Fig. 1.2C). This new channel has rapidly prograded outwards and the old Mullet Creek channel has begun to silt up and shows little recent progradation. According to Coleman and Wright's model of delta switching, this new channel will ultimately lose its gradient advantage by overextending itself, and the discharge will seek another distributary. This might eventually be the case on Mullet Creek Delta.

In conclusion, Coleman and Wright (1975) found that certain combinations of deltaic processes are common in delta models; six (out of ten) of their models of net sand distribution patterns were discussed in their paper. One of these models could be applied to Mullet Creek Delta, the model's characteristics being low wave energy, low tide rage, low offshore slope, low littoral drift, and a high fine-grained suspended-sediment load. In short, their major conclusions were that 'a relationship between delta sand body distribution and processes responsible for their geometry does exist and that more than one delta model is required for adequately describing deltaic sequences' (Coleman and Wright, 1975: p.147).

# CHAPTER THREE

# GROWTH AND FORM

## 3.1 Methods

This section of the study outlines the major features of Mullet Creek Delta and attempts to trace the main stages and mechanisms in its development. A brief outline of Lake Illawarra's evolution is also included as background material to growth and form of Mullet Creek Delta. This work is based on the interpretation of maps and aerial photographs, and observations in the field and from light aircraft. The study was limited in that the earliest aerial photographs available were from 1948 onwards (including 1951, 1963, 1972, 1975 and 1977) and the earliest reliable maps date from 1836.

Aerial photographs were mainly used to examine the growth of deltaic sand bodies, erosion of tributary channels, distribution of deltaic sediments, landform characteristics, and changes in landuse caused by urban development and rural activities. Maps aided in analysing shoreline changes, development activities, sediment deposition offshore, geology characteristics, lake bathymetry and bottom sediments and catchment area limits. Field observations allowed a closer examination of present-day delta characteristics.

## 3.2 Present-Day Form

The general form of Mullet Creek Delta is shown by Plate 3. The lower valleys of its catchment are infilled with unconsolidated sand, silt and clay of fluvial origin. The present-day delta has

Plate 3. The general form of Mullet Creek Delta (looking upstream); illustrating Mullet Creek's single flared mouth, wide floodplain and chenier development on Jerrets and Currung-goba Points, and infilling in Koong Burry Bay (extreme right) (12/6/1981).

an approximate length of 3.0 km. and an average height of 2.0 m.

Unlike many other deltas in coastal lagoons, Mullet Creek has broad deltaic extensions out into its receiving basin, rather than long and narrow subaerial jetties. The resulting form is a cuspate/lobate shaped delta (Roy and Peat, 1973). Average flood-plain width either side of the channel is around 600 m. and it is common for floodwaters to be dispersed onto these low-lying areas. Overbank flow is mainly concentrated on the lower reaches, as bank heights decrease downstream from 2.0 m. at the head of the delta to 0.5-1.0 m. near the stream's mouth. As a result of overbank deposition, ridges and swales have developed on the floodplain. These are found along the channel's banks and also further inland, consisting mainly of fine-grained material.

A notable characteristic of Mullet Creek Delta is that its deltaic channel is basically straight. This contrasts to the relatively meandering channel above the head of the delta. Furthermore, the delta has a single flared mouth and not a series of distributaries. Channel area also increases from the head of the delta to the single mouth. A subaqueous extension from the stream's mouth extends approximately 600 m. out into the lake. The radial bar mainly consists of sandy deltaic sediment which Roy and Peat (1973) believe was deposited when stream capacity was higher, as the sediment load of the creek today is primarily muds.

Since the deposition of this offshore bar, reworking of sediments by lake processes has occurred. The formation of chenier plains on Jerrets and Currung-goba points probably resulted from these processes (Plate 3). The plains comprise of a mud flat (or depression) of fairly fine sediment which has been enclosed by a ridge of sandy sediment. The mudflats develop when fine deltaic material accumulates on the shoreline, and the chenier ridges form when sandy sediment is reworked onshore by wind and wave processes. This is then followed by another period of mudflat development which causes the delta to further prograde, and a chenier plain develops (to be discussed in detail below). Two other chenier depressions are located in the middle eastern section of the delta. It is presumed that these may have formed at an earlier stage of delta development.

Other features of the delta include channel migration ridges on the convex side of the last meander along the Mullet Creek channel. This indicates that this part of the Mullet Creek channel has migrated in a southerly direction to where it is today, by eroding its concave bank and depositing on its convex bank. These migration ridges differ from the overbank depositional ridges, in that they were formed due to lateral accretion, that is, when coarse sediment accumulates within a meander bend and forms a point bar. Their evolution occurs when more and more sediment is deposited from upstream as a result of secondary currents and a scroll bar forms, which eventually becomes vegetated (Nanson, 1980). As more sediment is deposited new ridges are added and the convex bank moves outward resulting in erosion of the concave bank - this usually occurs at the same rate and is considered to be in a state of balance (Nanson and Beach, 1977). When floods occur vegetation formed on the migration ridges screen out sediment on the streams banks which can account for fine-grained overbank ridges formed near the banks. These overbank ridges seem to be fairly straight and lie parallel to the channel bank; this contrasts to the channel's migration ridges which are typically curved in shape. Thus migration ridges are formed due to flow in bend processes and overbank ridges form when peak discharges spill over onto the floodplain and deposition of fine-grained material occurs.

An "artificial" form of delta switching has also occurred on Mullet Creek, where the Tank Trap (a W.W.II anti-tank ditch) has diverted creek discharge and its entrained sediment, so that it enters the lake three kilometres north of the old delta. It is 650 metres long, has an average depth of 4.0 metres, and an average width of 25 metres, extending from the sharp bend at the head of the delta to Koong Burry Bay. Consequently, sediment has been debouched into the bay and a secondary deltaic deposit of sands and sandy muds has formed. Koong Burry Bay has progressively shallowed over the years as sediments have accumulated. The delta is both subaqueous and subaerial in character with sandy vegetated 'islands' forming in the middle of the deltaic deposit. Young (1976) notes the delta's size to be approximately 0.35 km. x 0.35 km. and it appears to be asymmetrical in shape due to reworking of sediment in a southerly direction by stream discharge.

## 3.3 Pattern of Change

The evolution of Lake Illawarra can be attributed mainly to fluctuations in sea level and altering deposition and erosion by streams. Mullet Creek Valley extended well beyond its present shoreline when the sea fell as far as 100 m. below its present level during the last glacial. 'When sea levels rose again the embayment cut by the streams [Mullet Creek and Macquarie Rivulet] was drowned and then impounded behind a barrier of marine sand swept up and deposited offshore by the rising sea. More marine sand flowed into the impounded waters through tidal channels' (Young, 1976: p.18). In addition, Mullet Creek and Macquarie Rivulet deposited fine material on the lake floor and built out deltas of coarse sediments. These deposits were partly eroded by renewed stream action across an exposed lake floor during subsequent low stands of the sea. Apparently three more cycles of lake formation and destruction, due to further glacials, occurred over the years before the sea reached its present level, about 6,000 years ago; with about 40% of the lake basin being infilled during these cycles. Roy and Peat (1973) have found evidence, through drilling and seismic surveys of a series of such fluctuations in the lake (See Fig. 3.1). In the period following sea level stabilisation the western shore experienced further progradation of deltaic sediments and deposition of fines onto the lake floor.

The northwestern shoreline during the last high stand of sea level is thought to have been as far inland as the Mullet Creek - Tank Trap intersection, as some deeply weathered soils overlying apparent estuarine deposits located on the southern side of the F6 expressway bridge indicate a Pleistocene age (R.W. Young, pers.comm.) (Fig. 3.2).

Perhaps also in the late Pleistocene it seems that Gibsons Creek flowed from the foothills and was joined to Hooka Creek (Fig. 3.2). Apparent traces of such a channel can be seen on the aerial photographs. In addition, bankfull discharge from Mullet Creek could have contributed to water flow in this channel. Possibly after one of the meander bends on Mullet Creek was breached (forming an ox-bow lake - south of Mullet Creek) the channel straightened and gradients increased in Mullet Creek causing meander bends to migrate downstream. As a result the Gibsons-Hooka Creek channel was intersected and

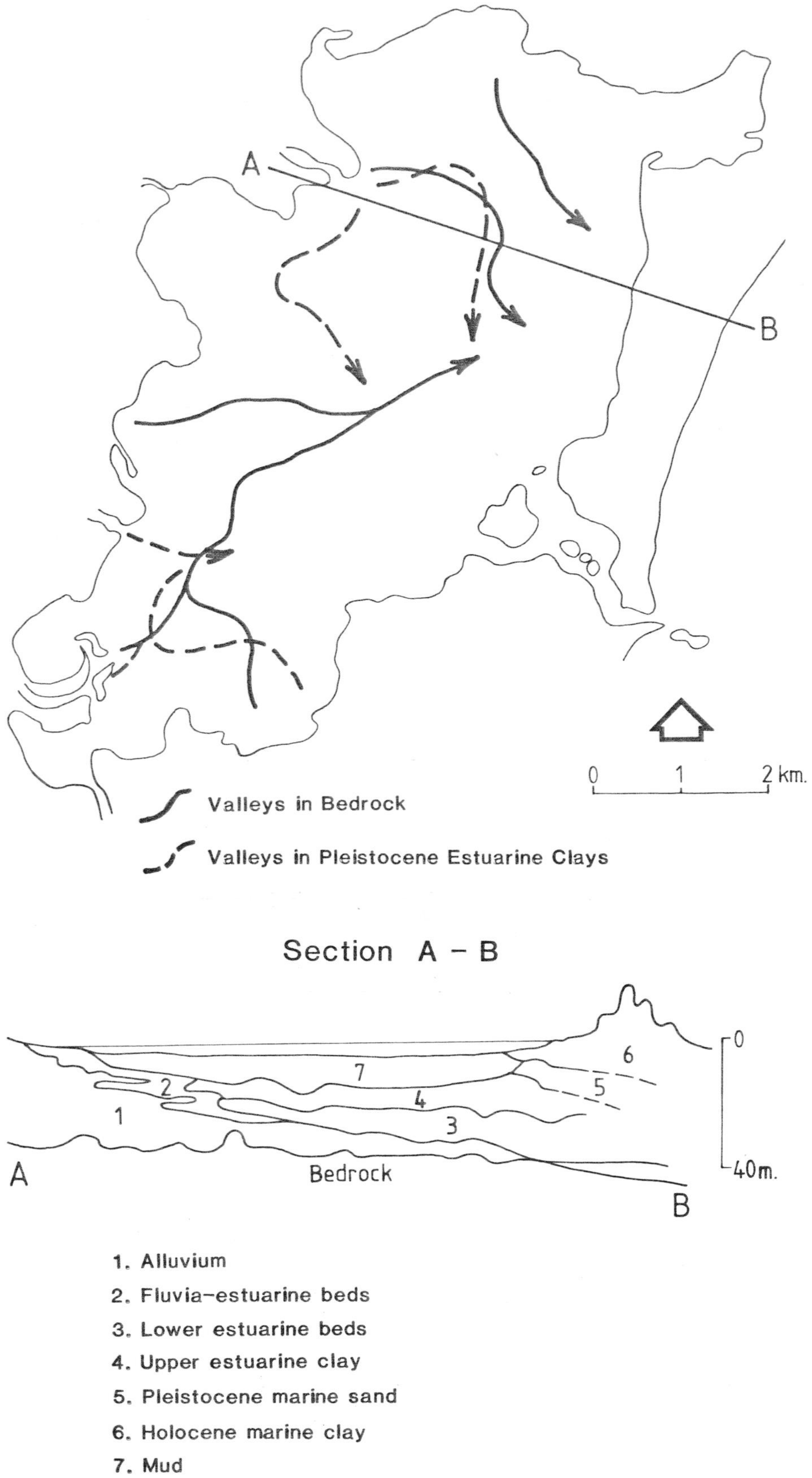


FIGURE 3.1: Lake Floor Stratigraphy & Morphology (after Roy & Peat, 1973)

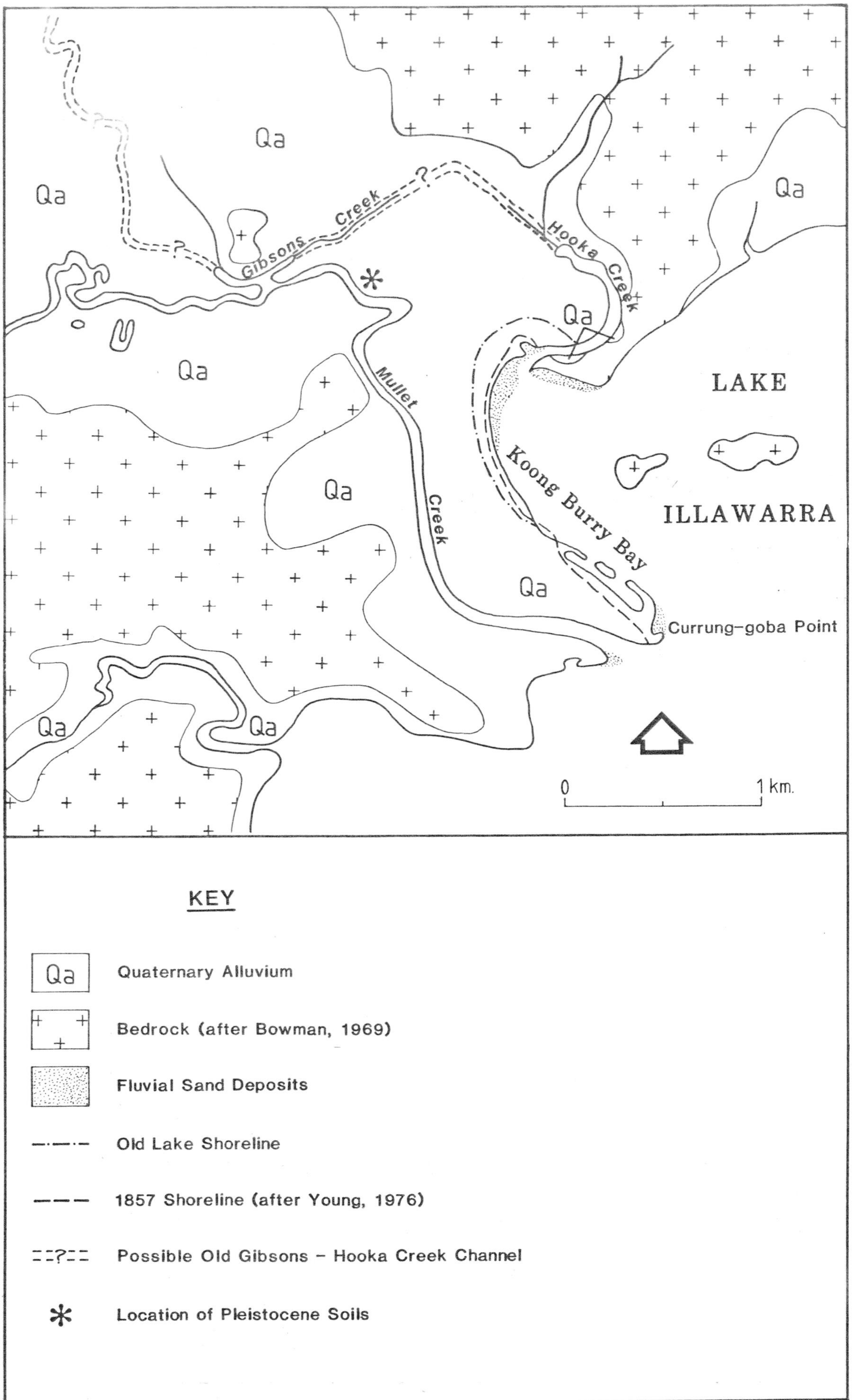


FIGURE 3.2: Development Characteristics of Mullet Creek Delta (before Tank Trap); Including Bedrock Boundary

captured by Mullet Creek, which ultimately restricted flow to the Hooka Creek end of the channel causing it to dry up and reduce in size. An alternate interpretation is that Mullet Creek once flowed along this relict channel and entered the lake near the mouth of Hooka Creek.

Following the Holocene drowning of the lake basin, increased sediment production from Mullet Creek was thought to be caused by the trenching of extensive alluvial valley floor fills and continued erosion of hillside deposits (Young, 1976). As the delta prograded into the lake the single stream mouth could have at one time faced an easterly direction and flowed into Koong Burry Bay near the northern tip of the more recent chenier plain. Channel migration ridges on the convex bank of the last stream meander on Mullet Creek suggest that the stream has migrated in a southerly direction to where it is now positioned.

Another form of delta progradation was by the formation of cheniers. Evidence of these on the delta are found on Jerrets and Currung-goba Points and in the middle eastern section of the delta. The latter possibly formed when the stream outlet flowed into Koong Burry Bay (Fig. 3.3 and Plate 3). An important factor for chenier development was an abundant supply of sediment which did not preclude the removal of the silt and clay fraction. Consequently a mudflat of sand, silt and clay progrades out from the shoreline (Fig. 3.4). This is usually followed by a period when stream deposition of fine-grained sediment is reduced: this allows waves to rework existing sediment onshore, and a sandy ridge is formed. Another progradation period of muddy sediments leaves the ridge surrounded by finer sediments as a chenier (Plate 4). Field evidence supported this

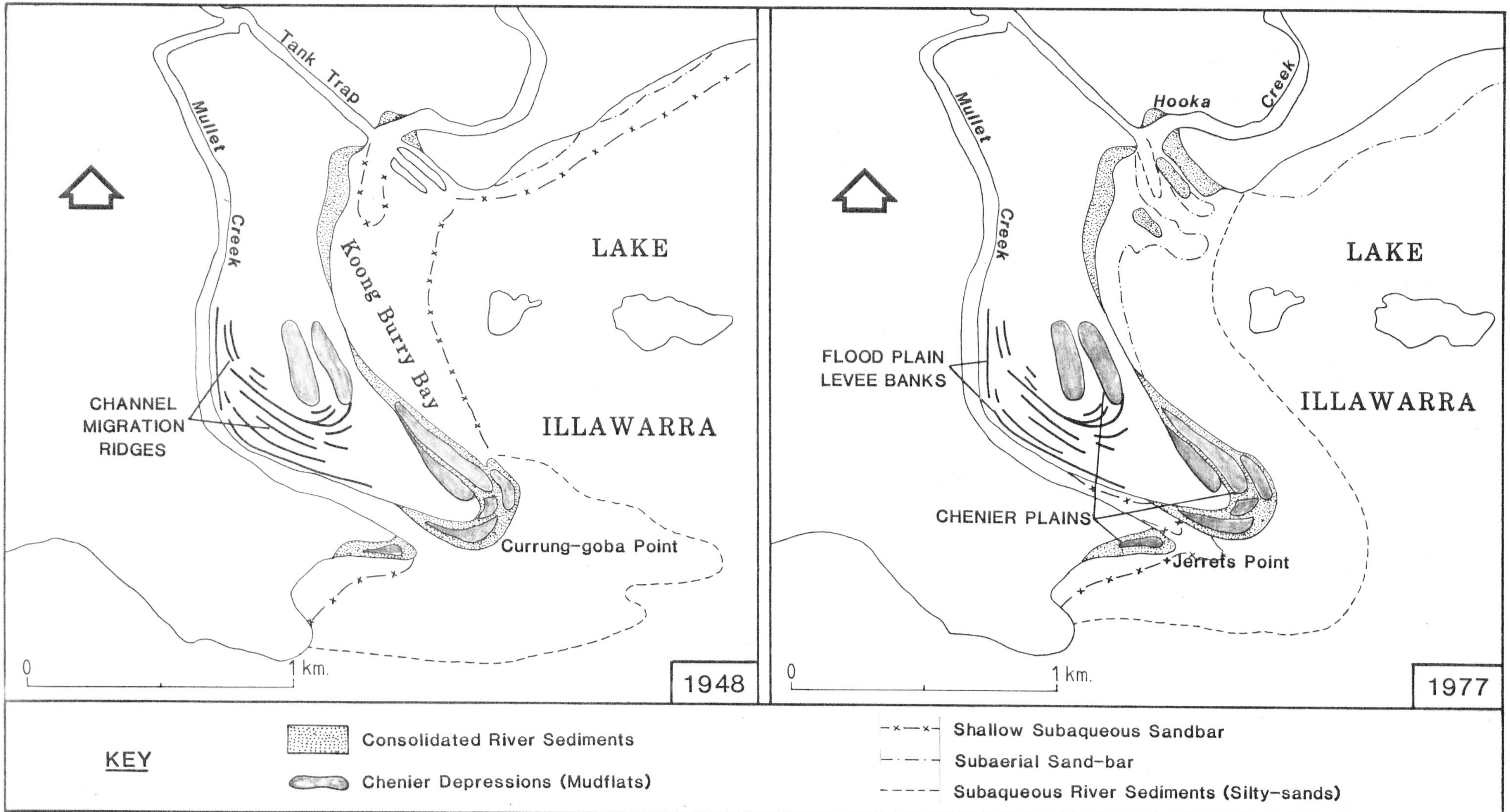


FIGURE 3.3: Delta Development on Mullet Creek Over Time (from aerial photographs)

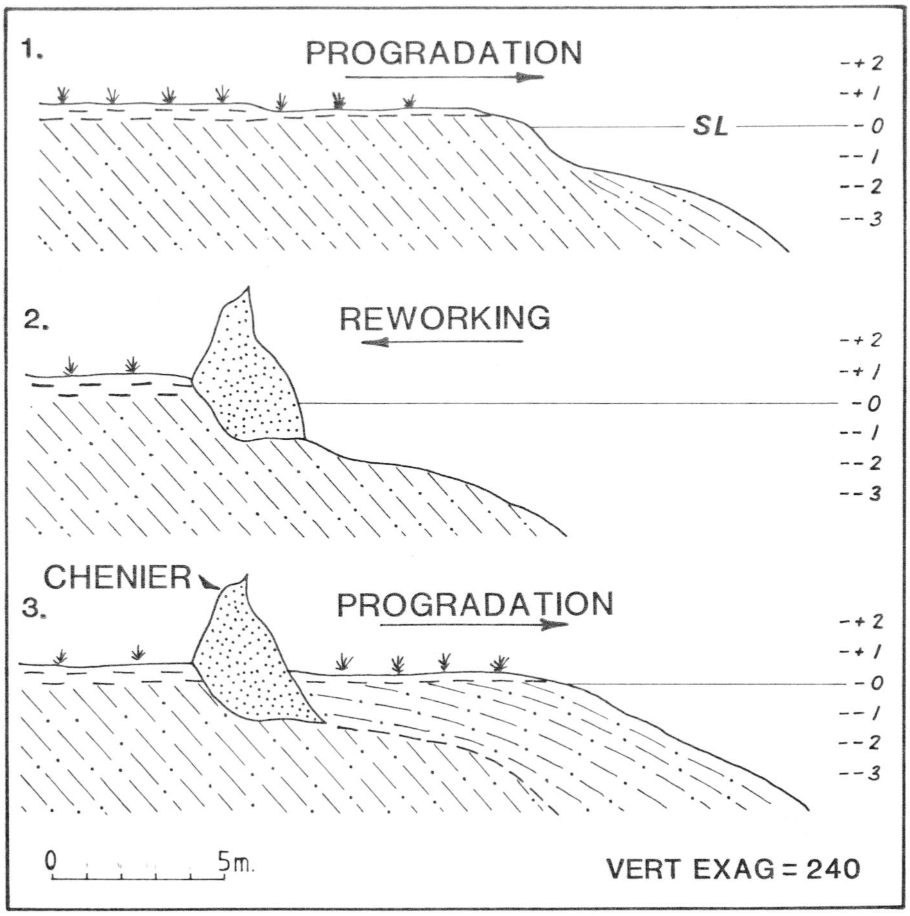


FIGURE 3.4

Schematic cross-section showing development of chenier.

1. Mud flat progradation.
2. Erosion & reworking of mud flat deposits & development of a ridge parallel to the shoreline.
3. The next stage of mud flat progradation, where the ridge becomes chenier.

(Modified after Hoyt, 1969)

development: sediment analysis on the eastern side of Currung-goba Point revealed a sand, silt, clay ratio of 52:10:38 for chenier ridges; 39:10:51 for the marshy depression behind the chenier, and 47% sand on the inland ridge; further analysis of drier chenier depressions on Jerrets point and the south-east facing extremity of Currung-goba Point also showed the dominance of silt and clays, with sand, silt and clay ratios of 22:22:56 and 12:25:63, respectively. As this process is repeated a series of sandy ridges with marshy sediments in front are produced and the delta slowly progrades out into the lake (cf. Hoyt, 1969).

As well as chenier development it seems that reworking of sediment debouched into the lake may have also contributed to the deltas present formation. That is, an old shoreline, extending from the northeastern corner of the delta (near the Hooka Creek outlet) down to the northern extremity of the chenier ridge plain (Fig. 3.2), appears to have been infilled over the years. It could be that deltaic sediments were reworked by receiving basin processes and deposited in the area when Mullet Creek's channel mouth faced an easterly direction. Moreover, Young (1976) notes that in the lake's development the barrier which impounds it was slowly extended and there was more than one outlet to the sea, which could indicate that tides had more of an influence on the lake's water circulation than occurs today, resulting in an even greater impact on sediment transport and deposition by currents and waves.

Marked increases in sediment yields from clearing for agriculture in the lake's catchment during the last century caused further progradation of stream deltas on the lake's western shoreline. This was unquestionably the case with Macquarie Rivulet. Comparisons

Plate 4. Extensive chenier development on Currung-goba Point; showing shallow, muddy depressions enclosed by coarser chenier ridges (12/6/1981).

of a map dating from 1857 with recent air photos and field surveys shows that Macquarie Rivulet Delta area increased 2½ times in a little over a century. Rates of delta growth indicate a 'very rapid increase until about the turn of the century, followed by a still substantial, though somewhat lower rate of increase until around 1940. Then came a period in which total area declined slightly, due apparently to erosion of the delta front by waves. However, from about 1950 onwards the delta again grew at rates roughly comparable to those of the first 40 years or so of this century' (Young, 1980: p.2).

During this same period Mullet Creek Delta did not increase appreciably in size. Young (1976) also compared maps from 1857 to the present day for Mullet Creek and found that the modern shoreline shows a general though not extensive advance (Fig. 3.2). This was also noted by Brown (1968), who added that disposition on the northern side was counteracted by erosion about the delta mouth.

In short, Mullet Creek has had a very slow rate of growth compared to Macquarie Rivulet Delta. This contrast seems curious because both deltas flow into the same receiving basin, experience similar weather regimes, and drain parent materials that yield fine sediments when weathered. Macquarie Rivulet does have a larger catchment area, steeper gradient and high discharges which may account for a higher sediment yield. Mullet Creek Delta experiences a longer fetch for winds to cause waves and currents to rework stream bourne sediment onshore. However, these factors cannot explain the fact that Macquarie Rivulet has experienced 2½ times growth in delta area in the last century whereas Mullet Creek has undergone comparatively little growth.

In trying to explain this dissimilarity Roy and Peat (1973) suggest that changes in climate and stream discharge may have led to the termination of active delta growth at the mouth of Mullet Creek. However, Young (1976) notes that climatic change would have been effective on a regional scale so that any changes produced on Mullet Creek would have been roughly matched by changes on Macquarie Rivulet. He instead suggests that lack of delta growth on Mullet Creek was most probably attributed to two engineering works on the lower part of the stream. Firstly, the damming of Mullet Creek at the turn of the century, a short distance upstream from the delta, could have trapped the coarser debris that was previously dumped at the mouth. Secondly, since the introduction of the Tank Trap, sediment discharge has largely bypassed the delta mouth and as a result a secondary deltaic deposit has formed at the Tank Trap mouth (seen from comparison of 1948 and 1977 aerial photographs - Fig. 3.3).

These two hypotheses could be related to the lack of delta growth, however it is possible to formulate another hypothesis from Nanson and Young's (1981) research, which showed the downstream reduction in channel capacity on Illawarra streams. Such a decrease does indeed occur on Mullet Creek (Fig. 3.5). Thus discharge must flow onto the wide, low-lying floodplains and as a result sediment would be deposited onto the floodplain instead of being carried to the stream mouth. This is supported by the fact that Mullet Creek is notoriously prone to flooding. Consequently, the majority of the sediment load deposited at the mouth would be fine-grained material with some coarser sediment being transported as bedload. It is important to note that no such marked decrease in channel capacity occurs on Macquarie Rivulet.

Nanson and Young (1981) noted that coincident with this

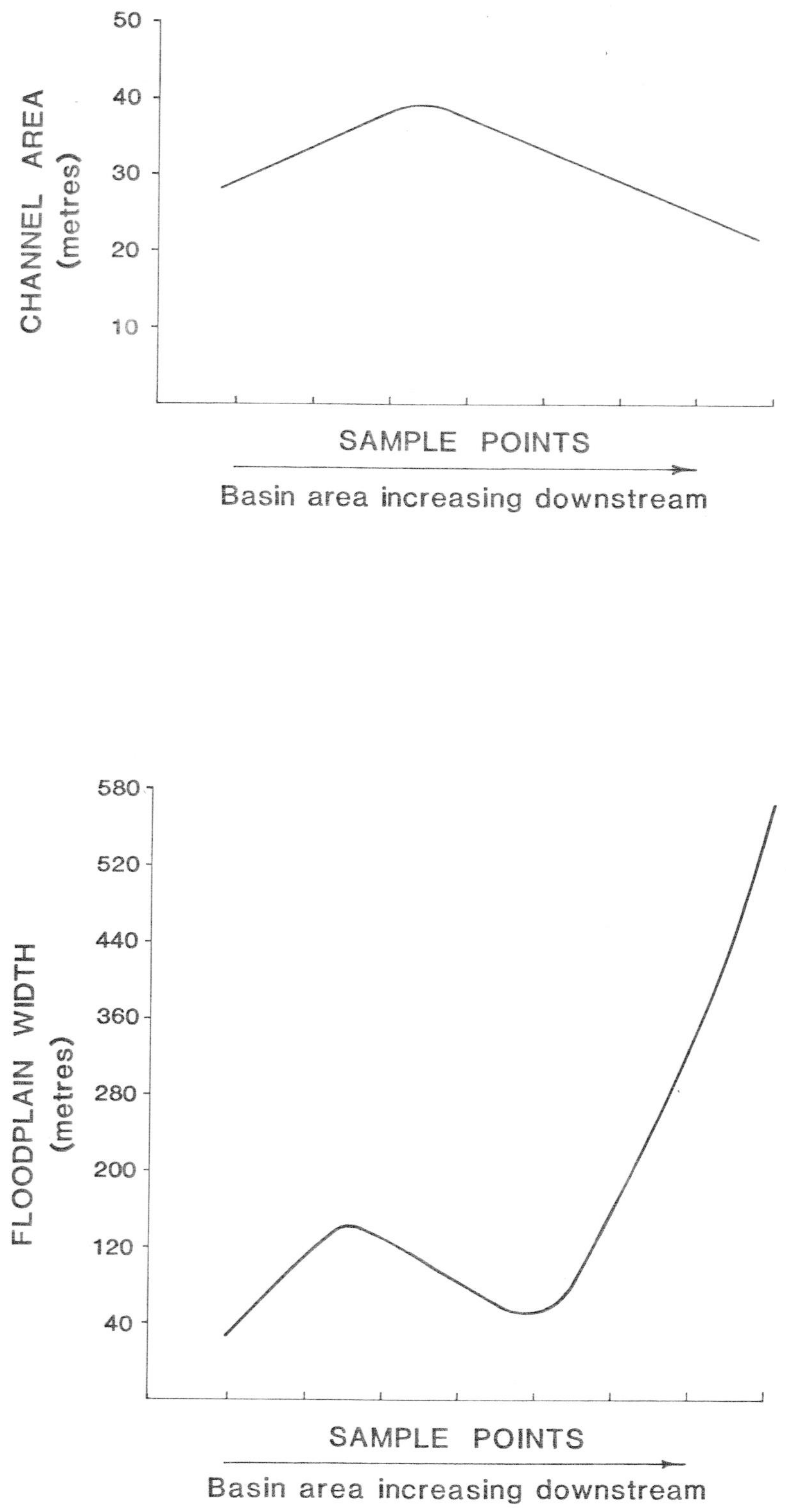


FIGURE 3.5: An example of decreasing channel capacity & increasing floodplain width downstream in the upper reaches of Mullet Creek (G. C. Nanson, pers. comm., 1981)

reduction of channel capacity was an increase in overbank forms on the floodplains. Evidence of this type of floodplain deposition on Mullet Creek could be found in the formation of stream levees on the channel reach above the F6 expressway, and ridges and swales on various sections along the deltaic channel below the Tank Trap intersection (Fig. 3.3). Sedimentary analysis of surface samples from a ridge and swale section on the eastern bank of Mullet Creek showed the deposit to consist mainly of fine-grained material with 12% sand and 88% silt/clay. Another relationship occurring with the decrease in channel capacity is an increase in floodplain width. This was found on the upper reaches of Mullet Creek (Fig. 3.5) and is evident on Mullet Creek Delta which has an average floodplain width of 600 metres. In comparison, Macquarie Rivulet has an average floodplain width of 200-300 metres with channel width, depth and cross-sectional areas increasing downstream (Neller, 1976). Therefore, sediment discharge in Macquarie Rivulet would be mainly contained in the deltaic channel and transported to its mouth; whereas on Mullet Creek it has been dispersed onto the floodplain.

Sediments that were transported to the stream's mouth were possibly carried further into the lake due to the jet flow effects of Mullet Creek's single mouth (resulting in its radial offshore bar - Fig. 2.4). This contrasts Macquarie Rivulet's multiple bifurcating mouth type. Coleman and Wright (1975) indicate that bouyancy and friction play significant roles in forming this latter stream mouth type. Young (1980) points out that Macquarie Rivulet once had a single mouth (in 1884). But after the delta swung around to the northeast it faced the longest fetch over which winds could generate waves running on to the southwest shore. As a result waves acting directly on the delta front began to interfere with normal stream deposition and the stream began to flow through two main outlets. This seems to contradict Coleman and Wright's (1975) hypothesis when applied to this bifurcating delta mouth. Their description of processes influencing radial bar types on single river mouths were fairly accurate for Mullet Creek, however, as frictional forces are dominant; and bouyancy plays a minor role, except during low river stage.

Mullet Creek also contrasts to Macquarie Rivulet in that it has not undergone delta switching during Holocene times. There could have been the possibility of Pleistocene stream flow being directed along the Gibsons-Hooka Creek channel but this is still uncertain. Young (1976) has found that Macquarie Rivulet's channel once flowed to the north of its present position. Abandoned stream channels of Macquarie Rivulet can be traced from the bend above the road bridge over the rivulet northwards for 1.5 km. to Wollingurry Creek. Around this area Macquarie Rivulet, along with Duck Creek formed a delta which was far more extensive than its present one. As this delta prograded eastwards the old lake basin was slowly infilled. Within perhaps the last 300 or so years (Young, 1976) the rivulet burst its banks at least one kilometre from its mouth and commenced building its modern delta. Coleman and Wright (1975) suggest that a high subsidence rate, low wave action, low offshore slope, small tidal range, and normally a finer grained sediment load favours this distributary pattern. All but the first are characteristic of Macquarie Rivulet's catchment and receiving basin. As Mullet Creek flows into the same receiving basin, some other factor must be operative. It could well be the great contrast in the width of the delta plains. As noted before, Mullet Creek has a relatively wide plain, apparently due to overbank deposition.

Macquarie Rivulet has much narrower sedimentary jetties which are more easily breached.

In more recent times, an artificial or man-made analogue of natural delta switching on Mullet Creek could be represented by the Tank Trap (Fig. 3.3). This World War II anti-tank ditch has redirected stream flow and its entrained sediment and formed a secondary deltaic deposit in Koong Burry Bay. As Coleman and Wright (1975) have indicated, delta switching of this type (i.e. single channels) causes the old channel (Mullet Creek downstream of the Tank Trap intersection) to silt up and show little progradation. Eliot et.al (1976) note that most of the discharge from Mullet Creek now enters the lake via the Tank Trap, which now acts as the main distributary channel for the stream. This is apparently so during low discharges, as the salinity readings taken by Eliot et.al (1976) during these low periods demonstrate (Table 3.1). These data showed that water flowing through the Tank Trap was far less saline than that encountered in the lower reaches of Mullet Creek. Moreover, the latter gave salinity readings four times greater than that at the Tank Trap mouth.

Although a detailed analysis is lacking, it could be assumed that a salt wedge (or body of saline water) reworks material upstream and deposits it at the tip of the wedge. Meanwhile, sand-size particles from upstream will be deposited at the front of the wedge. One of the processes causing this deposition is floculation (and defloculation), whereby fluvial sediments having electric charges which influence their behaviour in suspension interact with the salt water and the clay materials drop out of the sediment and accumulate. Thus channel siltation of this type may account for some deposition in the old Mullet Creek channel, for Eliot et.al (1976) point out that the former entry is now

| Site | Salinity $^{\circ}/_{\circ\circ}$ |
|---|---|
| 500 metres downstream from road bridge | 1.99 |
| 800 metres downstream from road bridge | 3.65 |
| 1,000 metres downstream from road bridge | 5.51 |
| 1,200 metres downstream from road bridge | 7.30 |
| North bank Gibsons Creek | 5.51 |
| South bank same site | 7.30 |
| Power line | 6.92 |
| Tank Trap (entire length) | 4.73 |
| Tank Trap mouth | 7.30 |
| Mullet Creek 100 m. below Tank Trap | 4.35 |
| Sand bar 300 m. below Tank Trap | 13.89 |
| Mullet Creek 600 m. below Tank Trap | 6.59 |
| Mullet Creek drive-in threatre | 29.21 |
| Mullet Creek mouth | 29.92 |
| Koonawarra Bay | 29.92 |

N.B. sea water usually 35.4 $^{\circ}/_{\circ\circ}$ salinity

Orion 407A specific ion meter and combination chloride electrode calibrated against sea water titrated against a known standard.

Table 3.1: Salinity Survey Mullet Creek (2.10.75) (after Illawarra Lake, 1976).

virtually a backwater flushed only during high flow and therefore a salt wedge has the opportunity to move upstream and cause sediment to accumulate.

It also appears that the Tank Trap has caused infilling at the sharp bend forming the intersection with Mullet Creek. Local residents have reported the depth at the sharp bend to have been at least four metres deep before the introduction of the Tank Trap; it is now about one metre deep. This entrained sediment carried along Mullet Creek was deposited at the deep intersection, with water discharge being concentrated down the Tank Trap (see Ch. 5 for more detail).

The Tank Trap has thus disrupted the flow of water and sediment discharge on Mullet Creek Delta. And this, in effect could have contributed to the termination of active delta growth at the mouth of Mullet Creek in the last forty years due to the formation of the secondary deltaic deposit in Koong Burry Bay. This hypothesis is now considered in the light of what is known of these sediments.

# CHAPTER FOUR

# SEDIMENTS

## 4.1 Methods

In the previous chapter it was shown that after the digging of the Tank Trap in 1941-'42 infilling of Koong Burry Bay increased. The problem whether this sediment actually had been transported through the Tank Trap or had been reworked from another source, such as Hooka Creek, can be approached by looking at the composition of the sediment. This account of the distribution of bottom sediments in Koong Burry Bay and around Mullet Creek Delta also provides basic data for management purposes.

A total of 56 samples were collected from the channels and banks of Mullet Creek (downstream from the F6 expressway road bridge), Hooka Creek and the Tank Trap, the lake shore, nearshore sand bars and areas of deeper waters (as far as 40 metres offshore) (Fig. 4.1). The location of sites aimed, in part, at filling gaps in earlier work by Jones et.al. (1976). Samples were collected along stream channels with a 0.4 m. cylindrical dredge, while a hand auger was used to obtain 0.1-0.2 m. surface samples and the deeper cores on offshore sandbar areas.

As the study is essentially descriptive in nature, the method of sedimentary analysis applied was similar to that of Roy and Peat (1973), which had already been proved successful in examinations of other enclosed lagoons along the east Australian coastline. This differs from the much more detailed sedimentary analytical technique employed by Jones et.al. (1976). The procedure involved deflocculation of aggregates where necessary, and passing each sample through a 2Ø

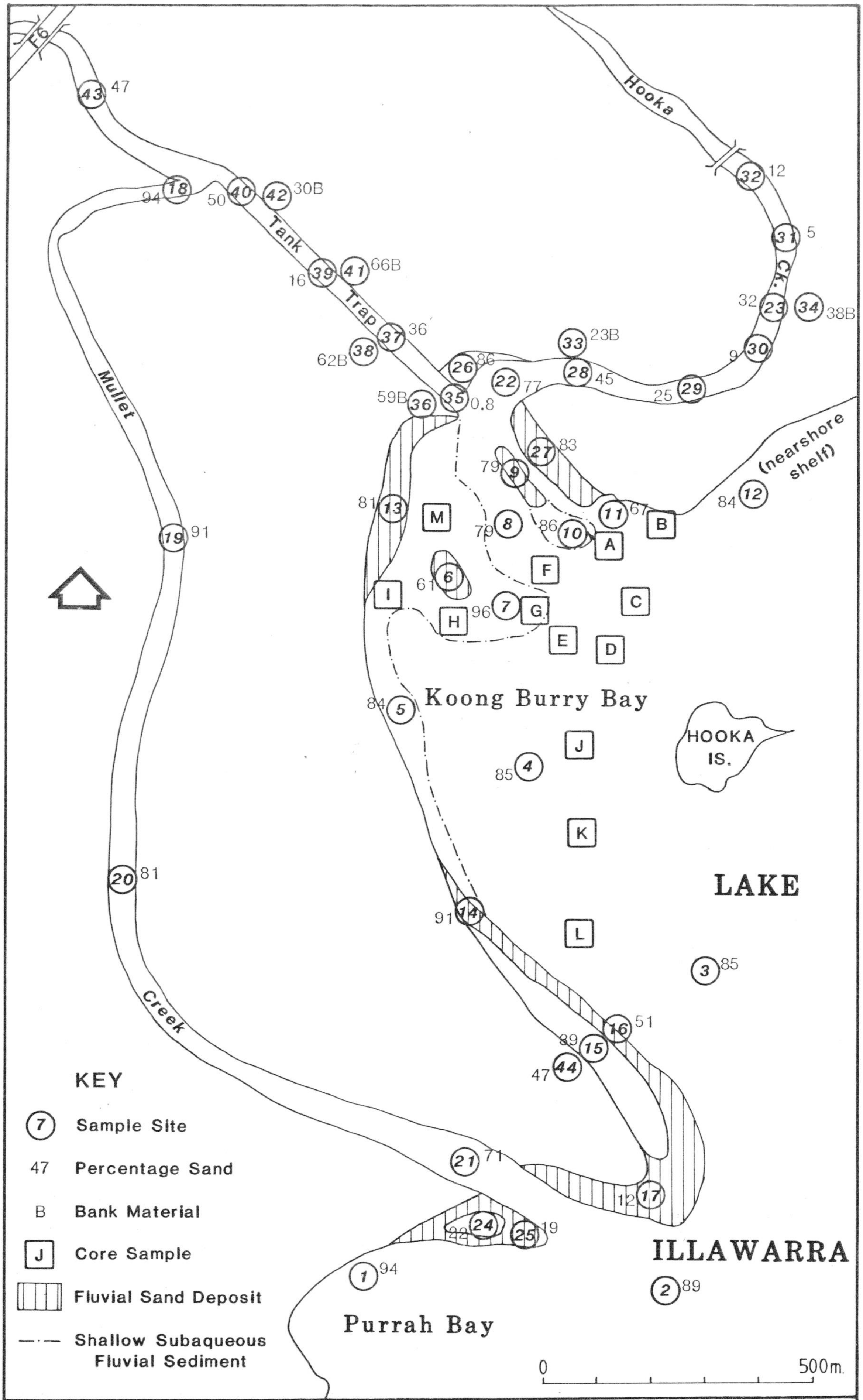


FIGURE 4.1: Location of Sediment Sites

sieve (retaining medium sand-size grains and larger) and a 4Ø sieve (retaining fine sand grains and larger). Silt and clay percentages were then determined for 50% of the samples by hydrometer and proportions of sand, silt and clay could therefore be estimated. Silt/clay ratios for the other 50% were calculated simply by estimating the amount of sand left (after washing the silt/clay through the 4Ø sieve) in proportion to the total sample and subtracting from 100. Composition, grainsize and sorting of washed sand fractions was estimated by microscopic examination.

The extent of 'loss of ignition' from each sample was given by placing a sample of known weight in a 630°C. furnace for 30 minutes and calculating the percentage lost in proportion to the original weight. Similarly, estimation of moisture content involved placing a sample of known weight in a 105°C. oven overnight and the proportion of moisture lost was then calculated as a percentage over the total weight.

A summary of the results of these analyses can be found in the Appendix.

## 4.2 Distribution

Examination of delta growth and form suggests that the cause of secondary deltaic deposits forming in Koong Burry Bay was transportation of sediment through the Tank Trap. This view is supported by the grain size of Tank Trap samples collected in 1975 by Jones et.al. (1976), in which percentages of sand were similar (80 and 93%) to those found on the offshore bars. Curiously, however, much lower percentages of sand were recovered from the Tank Trap during the present study. It is conceivable that sampling or methods of analysis might have caused some dissimilarity in results, but the degree of difference between the two sets of figures is so great that probably another factor is present. Moreover, the results for other areas around the delta are similar to the grain sizes reported for those sites by Jones et.al. (1976). For example, results in this study correspond closely to the high sand percentages in samples collected by Jones et.al. (1976) along Mullet Creek and on deltaic deposits at the mouths of Mullet Creek and the Tank Trap. In short, the difference in the results of the two surveys of the Tank Trap reflects a real change in sediment type.

Although floods in 1975 spread over the area cleared for the expressway, the disruption of the channel by bridge building did not commence until 1976, well after Jones et.al.'s survey. The bank disruption then contributed fine material which masked the coarse bed load, and has not been reworked through the Tank Trap because of the drought conditions since 1976. This explains why the Tank Trap has fine sediment whereas Mullet Creek and Koong Burry Bay have coarse sediment.

Sediment sampled from the shallow bar at the beginning of the old Mullet Creek channel (sample No. 18 - Fig. 4.1) shows that the very coarse bedload of predominantly quartz fragments and smaller fragments of lithic and opaque minerals carried by Mullet Creek has been deposited at the intersection and in the channel, in contrast to the fine/medium grained material now being transported along the Tank Trap. Microscopic analysis of Tank Trap sediments reveals a sediment load consisting of mainly fine to medium grained, poorly sorted, angular quartz fratments with some lithic and opaque minerals and 10-15% iron-stained fragments. This sediment composition continues 10-15 m.

along the Tank Trap bed indicating that coarser material is now penetrating into the Tank Trap. Further along the Tank Trap towards the lake, sediments are predominantly fine grained, poor to well sorted, angular to sub-angular clean quartz fragments with some lithic and opaque material and iron-stained particles.

Sediments in the old Mullet Creek channel differ considerably from those in the Tank Trap. Unlike Tank Trap sediments, high sand percentages in the lower Mullet Creek channel were consistent with the 1976 survey. This indicates that Eliot et.al.'s (1976) proposal that stream flow now being primarily directed through the Tank Trap is correct.

As Jones et.al. (1976) sampled extensively on the offshore bar at the mouth of Mullet Creek, sampling there in this study was very limited. Percentage sand on the bar was greater than that found at the channel mouth where there is a much coarser, less sorted and more angular composition of quartz and lithic grains. This may support Roy and Peat's (1973) suggestion that the deltaic bank is not a product of present day stream action but was probably formed when the capacity of the creek was higher. Roy and Peat (1973) also claim that the bank is currently being winnowed and reworked by wave action, which could account for the high percentages of fine to medium sand found in Purrah Bay. It is unlikely, however, that coarse grained sediment is being transported around Currung-goba Point and contributing to the Tank Trap bar as offshore sediments in the lower, southern half of Koong Burry Bay are very fine grained.

Sediment in Koong Burry Bay may have also come from erosion of the banks of the Tank Trap. Bank sediments sampled along the Tank

Trap contain similar constituents to those sampled on the offshore bar. Although the Tank Trap's original dimensions are unavailable, it is clear that the ditch has widened since it was dug. Army records (pers.comm.) state that 20 foot long wooden piles were revetted on the northern side of the anti-tank ditch at 4 feet intervals, but the present position of the Tank Trap bank is 2-3 metres north of these poles. It can therefore be assumed that bank erosion via the process of bank collapse has accounted for at least 2-3 metres of sediment on the northern side and possibly a similar quantity on the southern bank (Plate 5). In addition a deep, wide scour hole (see Chapter 5) has developed downstream of the old bridge crossing the Tank Trap, and this has almost certainly added sediment to the channel. The basically fine sediment from channel erosion has subsequently been reworked onto the offshore bar.

Another source of sediment for the offshore bar is thought to have come from Hooka Creek catchment. Aerial photographs show that in 1951 land on the northeastern shore of Hooka Creek south of Northcliffe Drive (refer Fig. 1.2C), was undeveloped, but in 1963 the construction of a Housing Commission village had appeared. Housing commission records (pers.comm.) show that clearing of the land for this development began around 1957 and completion of the homes around 1962-'63. Over those years heavy rains fell, which, according to Davidson (pers.comm. 1981), caused severe flooding. In February 1958 269.9 mm. fell in 2 days, March 1959 198.4 mm fell in 2 days, October 1959 492.4 mm. fell in 3 days, December 1960 146 mm. fell in 2 days, March 1961 243.3 mm. fell in 2 days, and in November 1961 a massive 1085.5 mm. fell in just 6 days. These intense falls probably caused reworking of sediment from the cleared hills into the stream,

Plate 5. An illustration of Tank Trap bank erosion (taken after heavy rainfall - 20/10/1981).

ultimately adding to siltation in Koong Burry Bay. Furthermore, the 1963 aerial photographs revealed firstly an increase in sediment in Koong Burry Bay and secondly a distinctive southerly deflection of sediments extending from the mouth of Hooka Creek obliquely across the Tank Trap onto the offshore bar. This suggests strongly that Hooka Creek contributed in supplying sediment to the offshore bar.

This hypothesis is supported by the fact that sediment bedload in Hooka Creek is similar to material on the offshore bar. Initially assumptions were that sediment carried along the stream bed of Hooka Creek would contain a lot of lithic material as its catchment area contains mainly latites. However, Budgong Sandstone is also present in the catchment area and the stream flows through Quaternary Alluvium which could account for the fine, angular to sub-angular quartz sands present along its lower reach. Although sediments from the creek contain more opaque material than do the bar sediments, it is presumed that a certain amount of dispersal and mixing with Tank Trap sediments has occurred.

Composition of offshore bar sediments in Koong Burry Bay was predominantly clean quartz that had not travelled very far. It consisted of grain sizes ranging from fine to medium, particles of angular to subangular shape, and sorting being fairly poor. Ten to fifteen percent of the samples were iron-stained particles which added an orange tint to the predominantly grey coloured sediment, and some lithic and opaque minerals were also present. At several positions on the bar (Fig. 4.1) core samples were taken by a hand auger to a maximum depth of one metre. When compared to surface sediments these cores show that percentage silt/clay increased with depth and that there was a very distinctive break at about 0.4-0.5 m. between the sandy surface sediments and the lower, finer sediments. This break seems to imply that Tank Trap deposition in the last 40 years represents a maximum of about 0.5 m. (Fig. 4.2, Appendix). It is presumed that a lot of pre-Tank Trap fine muddy material was deposited in Koong Burry Bay as a result of stream deposition at the mouth of Mullet Creek, and possibly Hooka Creek, or reworking of offshore sediments into the bay by lake processes.

## 4.3 Deductions from Distributions

### 4.3.1 Processes Present

Distribution of sediment in the study area can be related to delta-mouth discharges. According to Bates' (1953:p.2125) classification, flow of stream water from Mullet Creek (via either the Tank Trap or the old channel), into Lake Illawarra is defined as 'hypopycnal' inflow (inflow less dense), where 'sediment laden fluid moves out over the surface of denser fluid filling the basin ... vertical mixing is inhibited because of stability between the layers, and the flow pattern is that of the plane jet.' That is, bouyancy effects are dominant at stream mouths where hypopycnal inflow occurs. However in the case of the Tank Trap and the old Mullet Creek channel (pre-Tank Trap), the processes of outflow inertia and bottom friction have dominated the expansion and deceleration tendencies of the effluent, with bouyancy effects occurring at some point offshore where the flow slows down sufficiently to allow denser water to intrude beneath the effluent. Wright (1978) notes that continued discharge of sediment from friction dominated stream mouths causes shoaling in the region just beyond the mouth and consequently effluent deceleration occurs and sediment

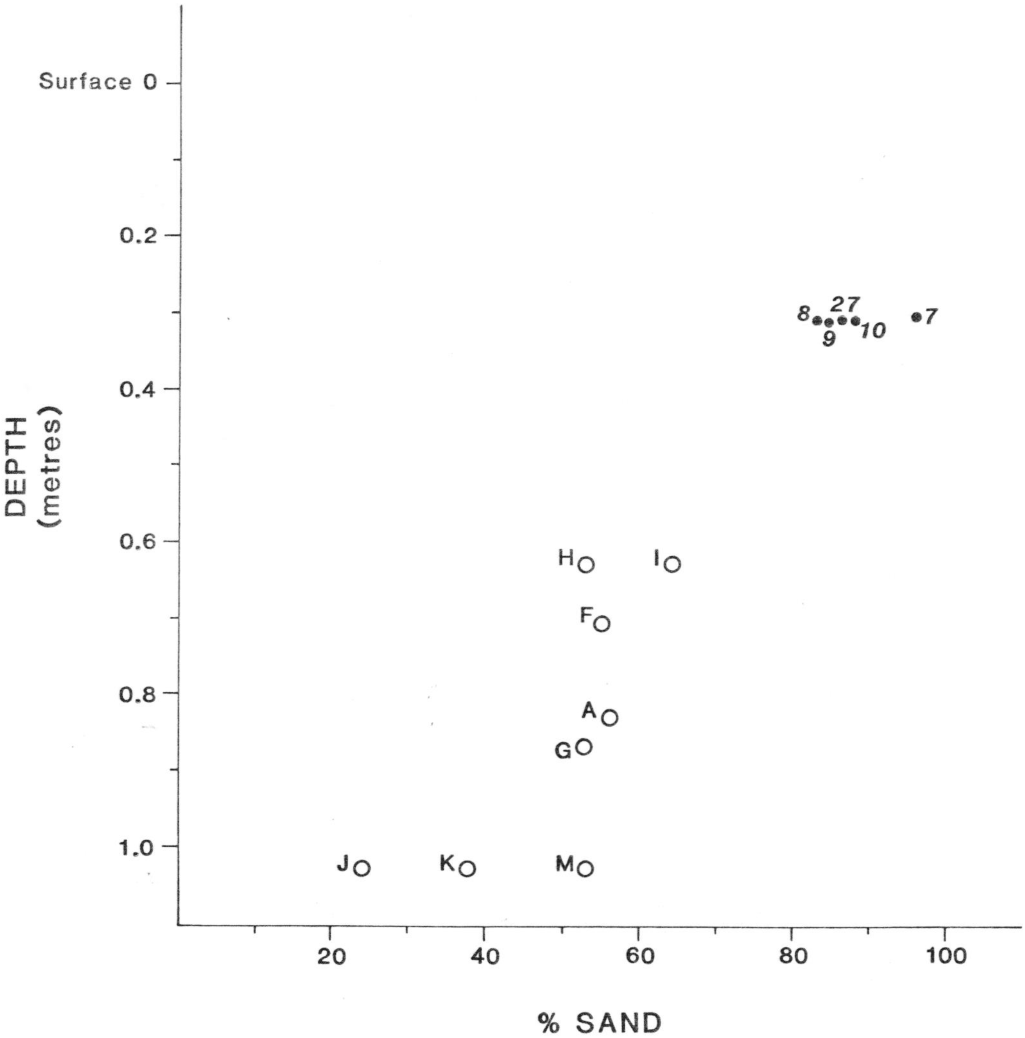


FIGURE 4.2: Comparison of Percentage Sand from Surface & Core Samples on the Offshore Deltaic Bar in Koong Burry Bay

spreading results, with coarser material being deposited near the mouth and finer sediment spreading further out into the receiving basin. As can be seen in Koong Burry Bay and at the old Mullet Creek mouth where effluent flows into a shallow receiving basin, the formation of a stream-mouth bar has resulted; a radial bar in both cases (see Plate 6 and Fig. 2.4, respectively).

### 4.4 Conclusion

Sedimentary analysis around Mullet Creek Delta suggests that:

(i) main channel flow into Lake Illawarra is now directed through the Tank Trap, with flushing of the old deltaic channel occurring only in periods of high flow;

(ii) channel flow would have initially tranpsorted stream-bourne sediment to the mouth of Mullet Creek; instead it has been directed through the Tank Trap into Koong Burry Bay;

(iii) increased clearing of the floodplain for urban development, farming activities and road construction since World War II has accelerated deposition of sediment into Mullet Creek, which has ultimately accumulated in Koong Burry Bay;

(iv) coarser sediment has been deposited at the Tank Trap-Mullet Creek junction, or at the entrance to the old deltaic channel, and only the fine/medium grained sediment has been transported through the Tank Trap;

(v) bank erosion along the Tank Trap has contributed to the development of the offshore bar;

(vi) sediments from Hooka Creek's catchment area and bank deposits are also responsible for sedimentation in the bay;

Plate 6. The formation of a radial bar off the Tank Trap in Koong Burry Bay (12/6/1981).

(vii) it is unlikely that coarse sediment has been transported around Currung-goba Point from the relict bar at the mouth of the old deltaic channel, but it is possible for fine material to have been reworked and winnowed out of this deposit;

(viii) formation of the offshore bar due to Tank Trap deposition in the last 40 years has accounted for 0.5 m. of sediment.

# CHAPTER FIVE

# CHANNEL MORPHOLOGY

## 5.1 Introduction

It was noted in Chapter Three that peculiarities affected delivery of sediment to the delta in the offshore area throughout Holocene times. A distinctive downstream decrease in the capacity of the fluvial channel was demonstrated (see Fig. 3.4). It appears that this decrease results in a very high percentage of flood discharge travelling over the floodplain rather than through the channel, thereby probably reducing the rate of sediment delivery to the delta, with much sediment being stored as fine overbank deposits in the alluvial tract. This chapter extends these observations by looking in detail at the present-day relation with channel form, flood discharge and sediment movement.

## 5.2 Methods

Channel cross-sections along the alluvial and deltaic channels of Mullet Creek and the Tank Trap were surveyed by a theodolite, recording waterlevels and width and depth parameters. In all 20 cross-sections were measured, 4 in Mullet Creek's alluvial channel (including 2 at the intersection), 9 in Mullet Creek's deltaic channel, downstream from the intersection and 7 along the Tank Trap (Fig. 5.1). Profiles extended from the floodplain bank on one side of the stream to the floodplain bank on the other side. Readings were taken from the northern side of the Tank Trap and alluvial channel sections and on the eastern bank along the deltaic channel. Water depths were

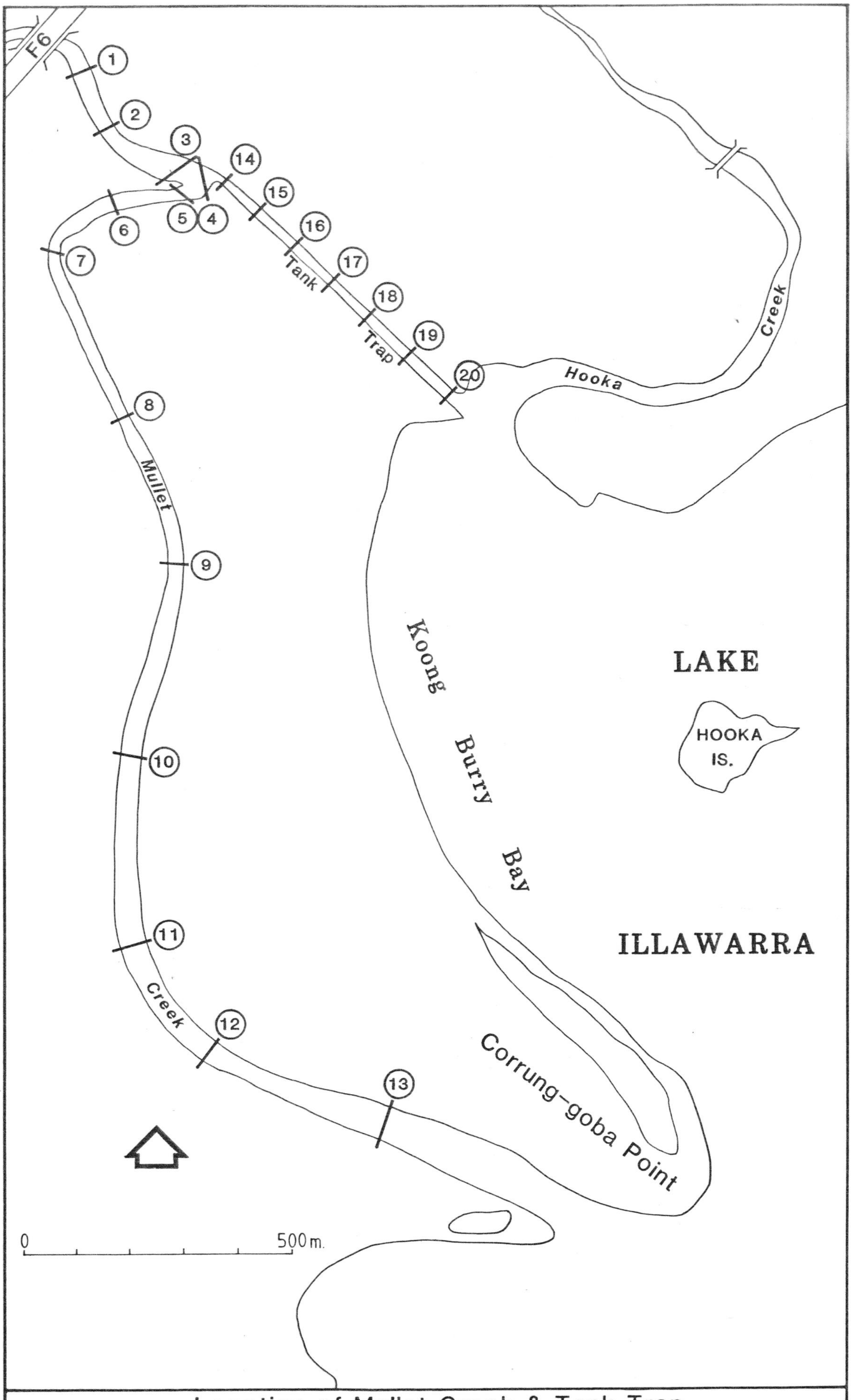


FIGURE 5.1: Location of Mullet Creek & Tank Trap Cross-sections (Numbered eg. 7 )

calculated at two points in the channel against a measuring staff.

The channel boundary was defined as the area filled at bankfull stage; channel area was given by the equation:

$$A = w \times \bar{d}$$

i.e. channel area = width x depth.

The floodplain was defined as the flat to undulating surface adjacent to the stream, most frequently covered during overbank discharge.

## 5.3 Discussion

### 5.31 Mullet Creek Channel

The alluvial channel 60 m. above the Tank Trap - Mullet Creek junction, is fairly wide and deep with high floodplain banks (Fig. 5.2, Sections 1, 2). As mentioned in chapter three the intersection has been filled in with medium to coarse, clean quartz. The junction (Plate 7) is very wide and very shallow with scouring occurring at the eastern concave bank (Plate 8) as a result of currents eroding the outside bank as high flows continue to enter the old deltaic channel. Consequently, sediment has been deposited on the inside of the entrance to the old deltaic channel, producing a very shallow 50-60 m. long bar (Plate 9). From this point downstream, depths increase slightly, but are still comparatively shallow with respect to the alluvial channel. Widths of the deltaic channel increase downstream, flaring considerably at the mouth (Plate 4). Channel form along this reach is therefore basically very broad and shallow.

In comparison to the upper reaches of Mullet Creek, above the railway bridge (refer Fig. 1.2C), the lower reaches appear to be much wider when observed from aerial photographs taken of the area. Results show that average channel area along the upper reaches above

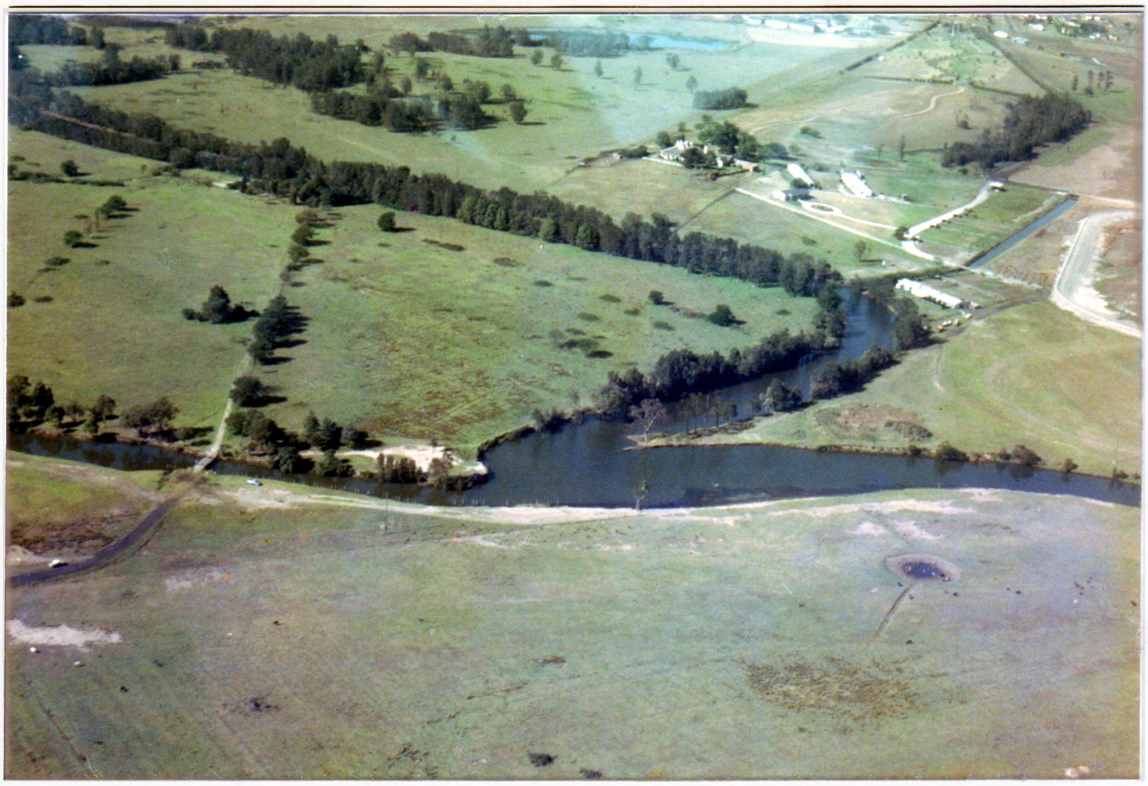

Plate 7. An aerial view of the Tank Trap junction. Note the tight curvature of the bend, and bank erosion - closure of the Tank Trap would increase this bank erosion. The scour hole just downstream from the old bridge crossing the Tank Trap is also shown (16/12/1977).

Plate 8. Concave bank erosion at the Tank Trap junction caused by channel flow being directed around the sharp bend down into the old deltaic channel during high discharges - refer also Plate 7 (taken after heavy rainfall - 20/10/1981).

Plate 9. A view of the entrance to the old deltaic channel; the Tank Trap flows to the left and upper Mullet Creek channel to the right (taken after heavy rainfall - 20/10/1981).

the railway bridge is 32 $m.^2$ (G.C. Nanson, 1981, pers. comm.), whereas average channel areas on the lower section are around 105 $m.^2$. Reasons for downstream increases in channel capacity are uncertain, but could be related to erosion caused by the extensive clearing of vegetation along the banks (cf. Nanson and Young, 1981).

(i) Width

In general widths in the upstream reaches decrease downstream, ranging from 23 m. at the higher reaches to 18 m. at the railway bridge (G.C. Nanson, 1981, pers. comm.). The alluvial channel, above the junction on the lower reaches, is about 36 m. in width increasing to an average of 69 m. at the intersection of the Tank Trap, where stream flow at the bend has caused a widening due to discharge being directed down into the Tank Trap. Along the deltaic channel, width increases from 40 m. at the entrance to 52.5 m. near its mouth; a further increase is experienced as it enters the lake. Notably, there is a vast difference between the upper reaches, having substantially narrower, decreasing cross-sections, and the increasingly wider cross-sections of the lower channel.

(ii) Depth

Mean depth also decreases along the upper sections with readings of 1.5 m. on its higher reaches to 1.0 m. above the railway bridge (G.C. Nanson, 1981, pers. comm.). Marked variations occurred along the lower sections, however. Above the junction average depth is about 3.2 m., decreasing substantially to 2.1 m. at the intersection of the Tank Trap which is more representative of the concave bank scouring as Fig. 5.2, sections 2 and 3, show an average water depth of about 0.5 m. at the intersection, produced by infilling. This is similarly the case at the entrance of the deltaic channel which gives a mean depth of 2.3 m., however the cross-section (Fig. 5.2, section 5) shows most of the channel bed infilled by a sedimentary deposit and water levels being less than 1.0 m. in most places. Stream depths then vary downstream (Fig. 5.2, sections 6-13), having an average reading of 2.1 m. along the channel reach. Overall channel depth also tends to decrease along this lower section but is generally a lot deeper than the upper section.

(iii) Channel Area

As shown in Fig. 3.4 channel area first increases and then decreases along the upper reaches from 44 m. in the highest reaches surveyed, to only 17 m. at the rail bridge (G.C. Nanson, 1981, pers. comm.). Consequently a corresponding relationship with increasing floodplain width downstream was seen to occur, as the majority of high discharges were dispersed as overbank deposition (cf. Nanson and Young, 1981). Although floodplain width was not measured for reaches below the bridge, channel area was comparatively greater. Readings of about 116 $m.^2$ were recorded for the lower alluvial channel above the junction, and an average of 144 $m.^2$ for the intersection. Again values varied along the deltaic channel, but there was a general increase in channel area downstream, ranging from 92 $m.^2$ at the Tank Trap junction (section 5) to 110 $m.^2$ near the mouth. One noticeable aspect of this lower channel is the very low eastern bank compared to reaches further upstream. This factor could give rise to the overbank deposition which is characteristic of Mullet Creek during high discharges (see Ch. 3).

(iv). In summary, therefore, results of the field survey support aerial photographic interpretation of the distinct change in channel form along Mullet Creek. Research shows much narrower, shallower

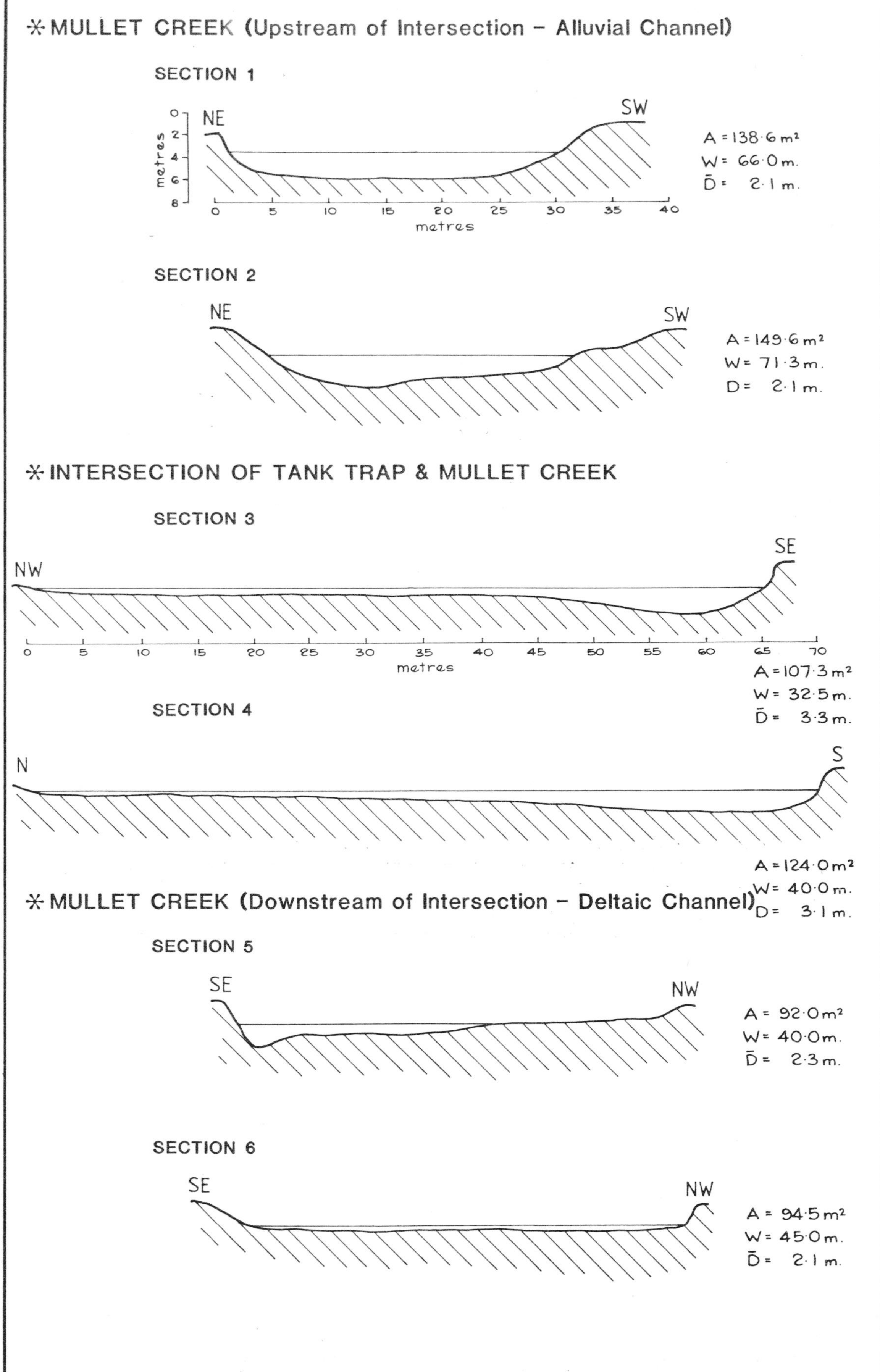


FIGURE 5.2: Channel Cross-sections along Mullet Creek & Tank Trap

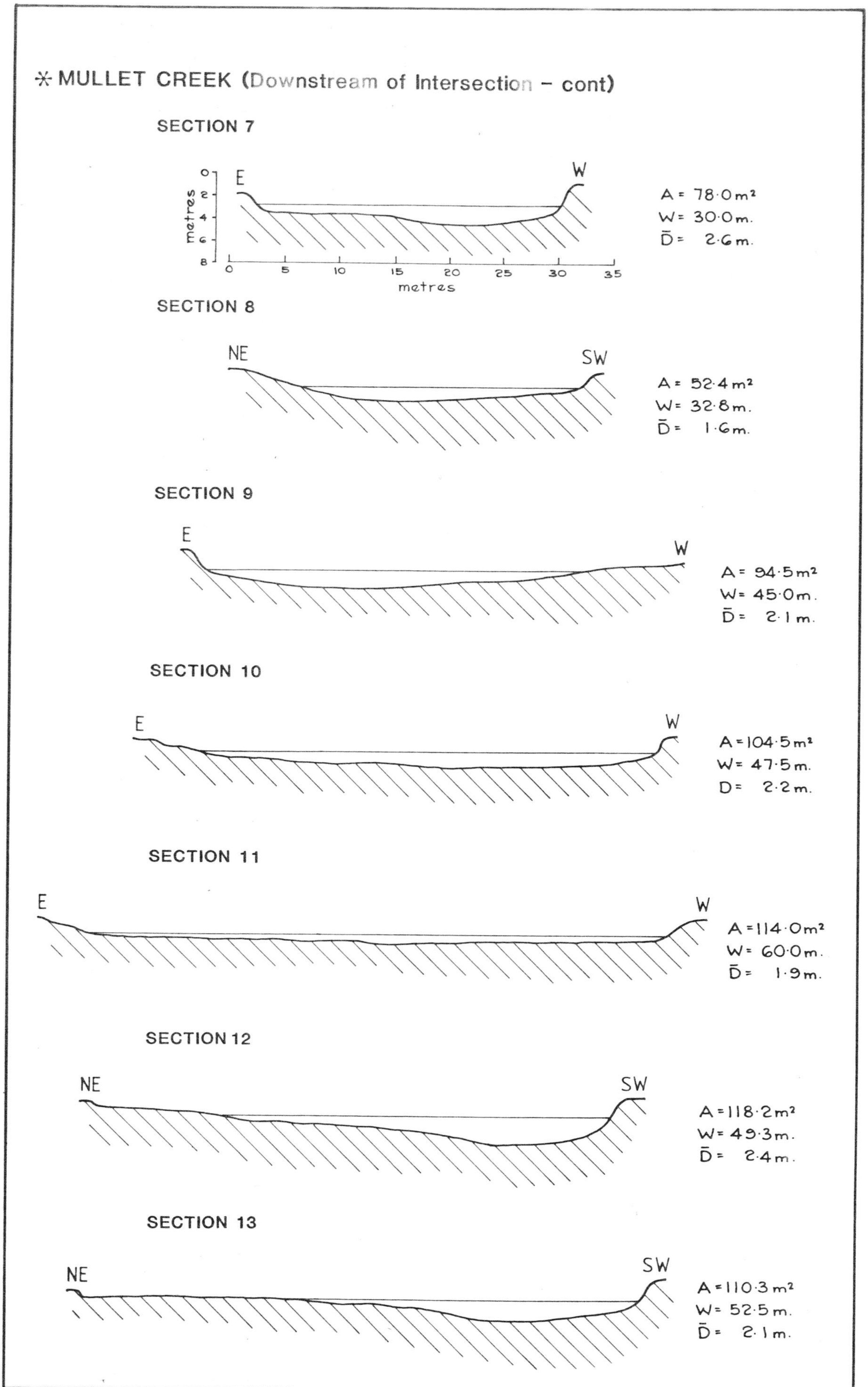


FIGURE 5.2: (cont.)

channel cross-sections above the rail bridge compared to a deeper, wider and larger channel along the alluvial and deltaic channel.

5.3.1.1 Historical Change

According to local residents, regular scenic boating trips were organised at weekends along Mullet Creek channel before World War II. This would imply that the channel must have been a lot deeper than it is today, as it is now very difficult for boats to venture right up into the channel. Comparison of the channel's past form is only via these sources as precise historical data are not available for Mullet Creek.

Presumably silting up of the channel began with the digging of the Tank Trap in 1941-42, after which stream flow was diverted away from the channel. According to Australian Army records (pers. comm.) the Tank Trap was to have been at least three metres deep, which suggests that coarse bedload reworked downstream has been deposited in the deep hole (reported to have been at least four metres deep) and entrance section to the old deltaic channel with finer sediment being transported down the Tank Trap and deposited in Koong Burry Bay. As the hole at the junction was slowly infilled flow patterns at the bend have possibly redirected the coarser sediment carried at high discharges, down into the Tank Trap as well as the old deltaic channel. This supply of coarse, reworked material has been the main cause of the 50-60 m. long subaerial bar at the entrance to the old channel. Furthermore, winnowing and reworking of the finer material from this deposit downstream would have also occurred. This supply, along with the intrusion of the salt wedge reworking lake sediment up into the channel (see Ch. 3) has been largely responsible for siltation that has occurred on the lower reaches below the 60 m. bar.

It can be noted, therefore, that deleterious repercussions are experienced within natural systems with the introduction of man-made alterations to the landscape, resulting in re-adjustment of the natural system (discussed in detail below).

5.32 The Tank Trap Channel

It was noted in Chapter Four, presuming Army files are correct, that 2-3 metres of sediment has been eroded from the northern and possibly southern sides of the Tank Trap ditch, giving the channel an average width of 25 m. (Plate 5). Depth is also constant along the channel, with an average of 2.8 m. If Army records are correct, and the initial channel was about 3 m. deep, very little deposition or scouring has occurred along the artificial channel. The only exception is the deep 5 m. hole located downstream of the old bridge crossing the channel (Fig. 5.2, section 6; Plate 7). The bridge was constructed so that access of supplies and livestock could be made to the southern Currung-goba Peninsula; both the bridge and the farm-house on the peninsula have been destroyed. Apparently the bridge was demolished when a large flood undermined bank material. Interference with flow at this site caused scouring of the 34 m. wide hole (width and depth figures for this hole were therefore not included in the previous Tank Trap dimensions).

In comparison to the old deltaic channel the Tank Trap is deeper (i.e. 2.8 m. in relation to 2.1 m. along Mullet Creek), but not as wide (25 m. to 44.6 m.), and similarly not as large (66.5 $m.^2$ to 95.4 $m.^2$). Likewise with respect to Mullet Creek's alluvial channel upstream of the junction, the Tank Trap is slightly deeper

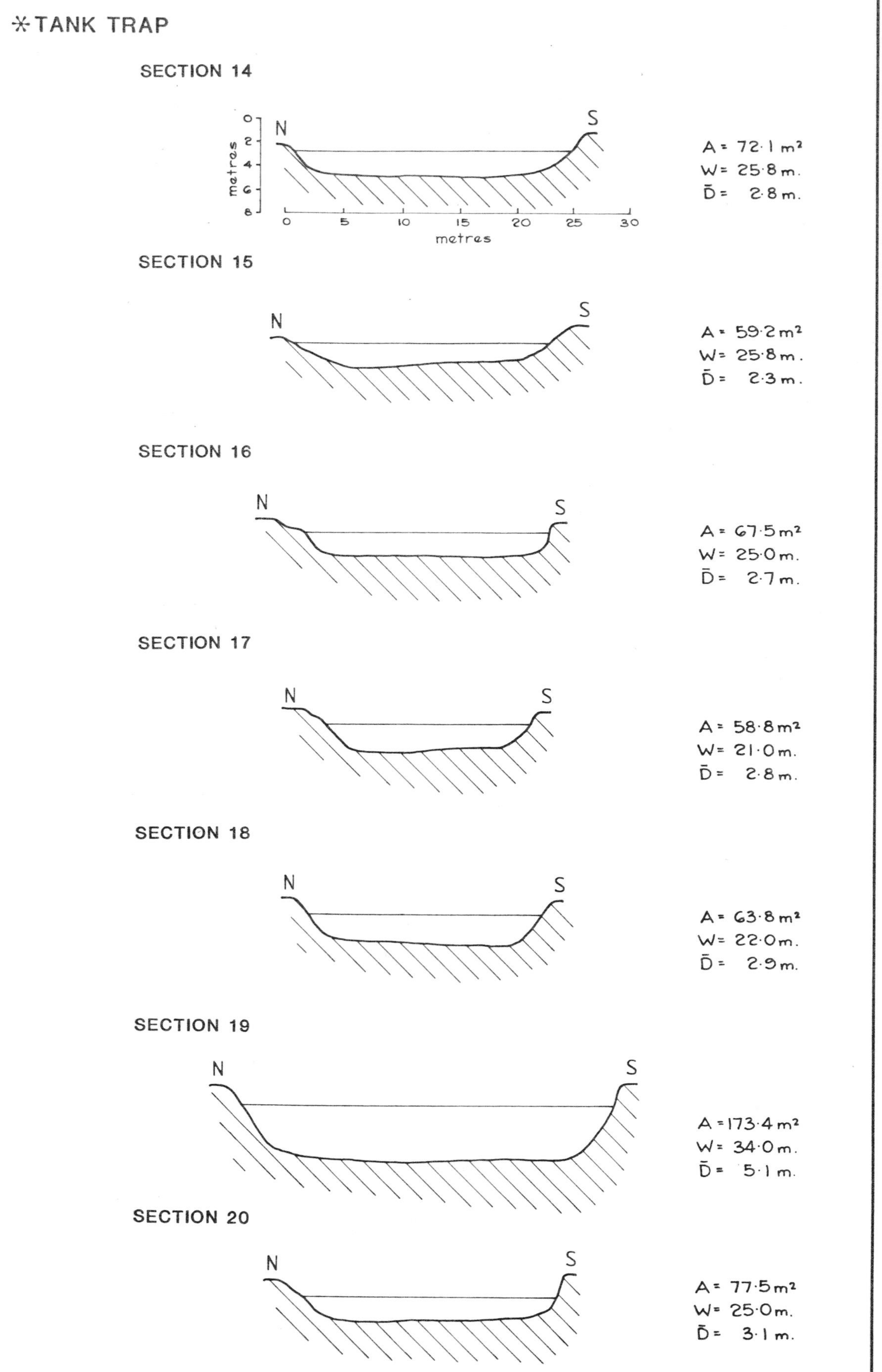


FIGURE 5.2: (cont)

(2.7 m. in Mullet Creek channel) but not as wide (52 m.) or large (130 $m.^2$). A vast difference is present with the upper reaches of Mullet Creek, where depth, width and channel area figures were considerably lower, recording 1.3 m., 22.6 m., and 31.9 $m.^2$ respectively (G.C.Nanson, 1981, pers. comm.).

Considering channel flow along Mullet Creek is now concentrated along the Tank Trap channel, alterations are certain to have occurred. However it is unfortunate that only speculations can be made, as an attempt to find the precise, original dimensions of the Tank Trap were unsuccessful. Some related historical information was available through Australian Army records (pers. comm.) which stated that construction of the Tank Trap began in late December 1941 and was completed in early May 1942. Its approximate length was to be about 3000 feet (914 m.) which would provide approximately 10 feet (3.048 m.) of water from the bend in Mullet Creek on a line to water approximately 4 feet (1.219 m.) deep north of Hooka Island. Furthermore, 600 feet (182.9 m.) of tetrahedrons were placed from the end of the ditch out into deep water. Channel length from the Mullet Creek bend to the mouth of Hooka Creek has accounted for only 650 metres. Over the years substantial widening of this channel has occurred with its base being fairly resistant to normal channel flow.

## 5.4 Conclusion

As a result of the introduction of the Tank Trap in 1941-42 channel flow has been redirected along the Tank Trap, with the old Mullet Creek channel being flushed only during high discharges. Siltation at the junction and the entrance to the old deltaic channel has occurred due to flow patterns causing deposition of coarse sediments within the stream. Winnowing and reworking of finer sediments from these sedimentary deposits has initiated further sedimentation of the old deltaic channel, along with the intrusion of a salt wedge reworking lake sediment up into the channel.

Independent research (G.C. Nanson, 1981, pers. comm.) in conjunction with the present study, shows that channel areas are considerably less in the upper reaches compared to the lower channels, however reasons for this are unknown. One conclusion that can be made from channel parameters is that the Tank Trap is adjusting to compensate for the increased concentration of flow through its channel. Cross-sections reveal an average channel area for the lower alluvial stream of 130 $m.^2$ (Fig. 5.2, sections 1-4), whereas channel area along the Tank Trap is 66.5 $m.^2$ (Fig. 5.2, sections 14-18, 20), explaining why high discharges are directed down into the old deltaic channel. Stream capacity along the old channel is 95.4 $m.^2$ which suggests why overbank deposition has occurred in the past along this reach (before the introduction of the Tank Trap), when taking into consideration the higher stream capacity in the alluvial channel (130 $m.^2$). When added to the channel area of the Tank Trap (161.9 $m.^2$), stream capacity increases for Mullet Creek's outlet into the lake, indicating that high discharge is able to be contained within the channels. This therefore alleviates the effect of flooding along the creek, although very high flow will understandably disperse onto the floodplain. With more material being contained within the channel it is expected that a greater quantity of sediment is transported to the channel mouth, which is subsequently adding to siltation in the lake.

Over the years, as siltation of the old channel has increased, the Tank Trap has adjusted by increasing in size, indicating that a unified system occurs between the two channels. Recognition of this fact is therefore important when taking into consideration proposals for future management of the system.

# CHAPTER SIX

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Summary of Results

The aim of this study was to describe and account for sedimentation near the mouth of a small coastal delta with the view to advising on the most suitable means of overcoming what has for some time been seen as a serious decline in environmental quality. Research has concentrated on the delta's growth and form, sediment distribution and channel geometry, thereby gaining an understanding of processes occurring throughout the system with the aid of theoretical models. Some of the main results established by the study were that:

(i) Mullet Creek Delta has developed primarily as a result of sea level fluctuations and altering deposition and erosion by streams. Since sea level stabilisation around 6000 years B.P. progradation of the delta from the sharp bend in the creek outwards into the lake has been due to sediments being transported to the mouth by stream flow, with overbank deposition being one of the dominant dispersal processes. The formation of cheniers and channel migration are also features of the delta's development, contributing to its single-channelled, cuspate/lobate shape (Roy and Peat, 1973). A relict, radial bar off the delta's old mouth is representative of stream deposition in the past when capacity of the stream was higher (see Chapter 2).

(ii) According to the scheme of Coleman and Wright (1975), Mullet Creek's stream system can be broken up into four main components, comprising the drainage basin, alluvial valley, deltaic plain and receiving basin. They noted that processes and other factors, occurring within the components of a river system, exert significant control on the geometry, genesis, and distribution of deltaic sediments (Fig. 2.2), with individual processes normally resulting in specific responses in a particular delta. Characteristic mechanisms of Mullet Creek Delta include its low wave energy, low tide range, low offshore slope, low littoral drift and a high fine-grained suspended sediment load (see Chapter 2).

(iii) The shallowing and formation of a secondary deltaic deposit in Koong Burry Bay has occurred due to the redirection of main stream flow and its sediment away from the original Mullet Creek mouth and through the Tank Trap (Chapter 3). The Tank Trap can therefore be considered as an artificial or man-made analogue of delta switching. As noted on other streams by Coleman and Wright (1975) this new channel has rapidly built deltaic deposits outwards into the lake, while the old deltaic channel has begun to silt up and show little evidence of growth. Siltation at the intersection of Mullet Creek and the Tank Trap and along the old deltaic channel has occurred via stream currents depositing coarse sediment in the stream, and probably in the latter case, intrusion of a salt wedge reworking lake sediment up into the channel during low flow (see Chapters 4 and 5).

(iv) Redirection of channel flow has contributed to the termination of active delta growth at the mouth of Mullet Creek in the last 40 years. However lack of delta growth during the last century, in relation to Macquarie Rivulet has been mainly attributable to its decreasing downstream channel capacity causing overbank deposition of sediment during high discharges, in conjunction with factors such as Mullet Creek's comparatively lower discharges, smaller catchment area, lower relief and greater impact from a longer wind fetch (see Chapter 3).

(v) Increased clearing of the floodplain for urban development, farming activities and road construction since World War II has accelerated deposition of sediment into Mullet Creek, which has ultimately accumulated in Koong Burry Bay. This is an example of why the Illawarra Lake Report (1976: Section 12.2.2(a), p.139) recommends that 'removal of soil, urban development and any recreational activity that will disrupt the banks or flood-plain surface, should be excluded from a zone at least 100 metres wide along each bank of all main waterways'. Further neglect of this advice with respect to Mullet Creek, as well as other streams flowing into the lake, will ultimately increase siltation of the lake, causing an even greater decline in environmental quality (see Chapter 4).

(vi) Sediment transported from Mullet Creek through the Tank Trap has been largely responsible for sedimentation in Koong Burry Bay though sediment from Hooka Creek and the Tank Trap's banks has also contributed to siltation in the bay. Formation of the offshore bar due to Tank Trap deposition in the last 40 years has accounted for a depth of about 0.5 m. of sediment. Sedimentary analysis revealed that the offshore bar is comprised of predominantly fine to medium, poorly sorted, angular to sub-angular quartz. Furthermore, reworking of the bar in a southerly direction has occurred as a result of stream discharge from Hooka Creek (see Chapter 4).

(vii) Another result of redirection of channel flow is that the Tank Trap and the old deltaic channel operate as a unified system whereby widening of the Tank Trap via bank erosion has been initiated as a result of the two channels attempting to cope with higher channel areas upstream (see Chapter 5). Drastic alteration of one channel would certainly affect the other.

## 6.2 Recommendations

The following recommendations are based on the recognition that the channels of Mullet Creek and the Tank Trap need also to be considered in terms of their ecological-recreational value and their role as the major outlet for flood waters from the Dapto area.

The Illawarra Lake Report (1976) notes that the area of Mullet Creek, Currung-goba Point and Hooka Point is an important nesting, resting and feeding ground for a great variety of birds, and along the banks of Mullet Creek, is well populated by the eastern water rat. It was also pointed out that it is one of three main relatively undisturbed areas remaining on the lake shore and its preservation as a vegetated area is essential, providing great scope for passive recreation land.

In the light of these qualities and the results reported here a number of recommendations are suggested:

(i) Excavation of the secondary deltaic deposit in Koong Burry Bay appears acceptable, even advisable. Although the deposit does not represent a potential sand source, due to sediment comprising of fairly fine, clean sands with mud increasing in depth and its aerial extent not being very great, dredging could probably provide a supply of loam as top dressing, after desalinisation (Illawarra Lake, 1976), if marine sulphates are not encountered (Norwood, 1975). The Illawarra Lake Report (1976, Section 12.2.8(i): p.141) points out that this sediment deposit is unproductive as a food source for bird life as the bird population is very much lighter compared with other parts of the lake. Thus, a solution to shallowing in the bay would be acheived, providing a use for the excavated sediment, without causing a major disturbance of the wildlife in the area.

In all sediment could be removed from the bay to a depth of 1.0 to 1.5 m., in an area to the west of a line extending from Hooka Point to a region about 250 m. north of Currung-goba Point on the opposite shore (refer Fig. 1.2C). Exceeding this 1.0 - 1.5 m. limit would create a hole deeper than surrounding areas in the lake. Due to the environmental quality of Hooka Island, excavation should probably not encroach further than 50-100 m. from its western shore. As Young and Reffel (1981) note, dredging would need to be closely supervised, as excavation would result in sediment stirring and furthermore the outer limit of excavation would need to be maintained.

(ii) Although excavation of sediment in the bay is the immediate remedy the problem of further sediment being transported downstream through the Tank Trap still remains. The obvious answer would be to close the Tank Trap, but this could present a number of serious repercussions:

(a) As mentioned in Chapter Five, the old deltaic channel and the Tank Trap operate as a unified system, so as to cope with stream capacity upstream. Closure of the Tank Trap would mean a reduction in channel capacity into the lake during high discharges, resulting in an even greater build up of flood waters back along the creek (refer Fig. 1, drawing No. D90/11, Mullet Creek Surface Flood Levels March 1975, City of Wollongong Council Records). Admittedly severe floods haven't occurred over the last 5 years, but nevertheless, there is the certainty of them in the future. This means that residential, commercial, industrial and rural properties would be affected even more than they have been in the past by the build-up of floodwaters upstream.

(b) In association with this problem, the influence of urban land development draining to Mullet Creek has altered discharge patterns. According to Eliot _et.al_., (1976) local flooding has increased in Dapto over the years partly as a result of increased runoff from urban land. Eliot _et.al_. (1976) note that increased stream discharge due to urbanisation firstly causes local floods adjacent to streams, and secondly with increased discharge there is greater erosive power which influences lake sedimentation. Although built-up areas are only small around Dapto (8% in 1975) discharge is affected, and planned expansion will account for about 12% of the catchment.

It is seen, therefore, that local flooding will increase in the future, and if the rates of flow through channels leading to the lake are decreased the results could be disastrous. When viewed in this context it is desirable that the Tank Trap remain open. Indeed, if the Tank Trap was sealed at its upper end, the likelihood of severe bank erosion as flood waters swept around the very tight bend into the lower reaches of Mullet Creek is great. Costly revetments would be needed to contain this erosion.

(iii) Moreover, it is recommended that construction of structures be prohibited along Mullet Creek, the Tank Trap or on the low-lying parts of Currung-Goba Peninsula, as these would further impede flow of floodwater into the lake; this would include roadwork across the stream or construction of a tourist complex on this site. As a positive measure removal of all unwanted structures restricting flow within these channels should be carried out, for example, car bodies, industrial waste and household garbage as well as the old collapsed bridge within the Tank Trap, which would prevent further hindrance to flow and scouring and erosion of the channel.

In addition to the above point, it would be advisable to heed suggestions made by the Illawarra Lake Study (1976) by, firstly, restricting all power craft from Mullet Creek and the Tank Trap, other than those moored by fishermen in the creek, so that the already serious bank erosion is not accelerated (Section 12.28(g), p.141). Secondly the New South Wales Soil Conservation Service could be approached to have stabilising and restorative works carried out along Mullet Creek and the Tank Trap where bank collapse is most advanced (Section 12.2.2(c), p.140).

(iv) One way of increasing flow through Mullet Creek in addition to maintaining discharge through the Tank Trap would be to remove sediment at the Tank Trap junction and along the 50-60 m. bar at the entrance to the old deltaic channel by suction dredging. In comparison to sediment in Koong Burry Bay this sediment is predominantly medium/coarse grained quartz and could prove to be a valuable sand source. The depth of this sediment is unknown, however excavation of up to 2.5 m. below water level could be possible without affecting stream gradients upstream. Depending on the composition of quality of sand at depth downstream from the entrance bar, dredging of the whole reach could be also undertaken; thereby alleviating the problems of siltation within the channel and low channel capacities during high discharges. As emphasised earlier, dredging of the sediment would need to be closely supervised to avoid the unnecessary turbidity, and in this case, the fact that depth changes extending below the 2.5 m. limit could initiate further problems up and downstream.

(v) If dredging is carried out within the channel and Koong Burry Bay, the problem of sediment transported downstream will again arise in the future. However, as results have shown the coarser sediment lodges at the Tank Trap junction and at the entrance to the old deltaic channel, the majority of future coarse sediment would possibly lodge here and not be carried into the lake. This sediment could in time again be dredged by an individual or company seeking a small sand resource. Placement of a sediment trap in the creek below the F6 bridge would impede finer sediment from entering the lake, but this is a relative high cost solution, both in construction and maintenance, and one which would also reduce the recreational value of the area.

(vi) As pointed out by Young (1976) and Section 6.1(v) above, increasing neglect of land use throughout the lake's catchment, for example, straightening of small channels, the dumping of rubbish in stream channels, lack of sediment traps downstream of quarries, mines and waste dumps, removal of forests and vegetation on steeper slopes of the escarpment, disruption of stream banks or floodplain surface by soil removal, urban development and recreational activity, and the lack of implementing drainage systems that retard water and sediment delivered into the stream system by new subdivisions in the lake catchment causes massive slugs of sediment to be freely transported into the streams and subsequently the lake. Although these measures have been stressed before, little attention has been paid to remedying the problem areas.

It is well known (e.g. Wolman, 1967) that there is an initial reduction of channel size during urban expansion due to alteration of stream channels and increased erosion of sediment from the cleared landscape, forming sand bars and dunes which blanket the bed of the channel. If vegetation becomes established on the bars, channels become constricted, thus reducing the width/depth ratio of bankfull stage and overbank flow occurs. However as urbanisation proceeds, erosion of channels follows, and the deposits are scoured out. Nanson and Young (1981) observed these trends on Illawarra streams, and warned that urban growth could result in massive amounts of sediment being carried into the lake. Given the very considerable urban expansion planned for the Mullet Creek catchment, the most serious phase of sedimentation has probably yet to come. Thus apart from the immediate effects of dredging, the solution to the problem of sedimentation lies essentially in the control of disruptive landuse in the creek's catchment. It is therefore suggested that stricter controls and policing of land development in Mullet Creek's catchment and the remaining lake catchment area be immediately implemented, before much more serious environmental repercussions eventuate.

## 6.3 Conclusion

Although this study has been concerned with problems encountered on one small stream, Mullet Creek could well be considered as a type example of situations which will be increasingly encountered as urban pressures on the coastal lagoons of N.S.W. grow. This case demonstrates that a good knowledge of channel form and dimensions, of flood behaviour, and of depositional patterns is essential if a deterioration of environmental quality is to be avoided. While much of that knowledge will come from direct field observation, it needs to be based on and linked to the general theory of delta development under conditions such as those encountered here. This study has also shown that deltas developed in coastal lagoons may diverge from the normal sedimentary-jetty type (Davies, 1977). The Mullet Creek delta is unusually wide as a consequence, it seems, of a very high incidence of overbank flooding caused by the peculiarities of its channel form. Moreover, rates of sediment delivery have been surprisingly small largely because of the downvalley reduction of the channel through the alluviated section of the valley. The characteristics of alluvial channels may thus have a greater influence on delta growth than has been recognised by Coleman and Wright (1975).

| Sample | GRAIN SIZE ANALYSIS Wet sed. wt. | Dry sand wt. | >2mm. | ORGANIC CONTENT Init. | Burnt | MOISTURE CONTENT Wet wt. | Dry wt. | RESULTS % Moist | % Sand | % Silt | % Clay | % >2mm. | % Organic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 60.1 | 44.5 | - | 20.017 | 19.572 | 15.276 | 12.029 | 26.99 | 93.68 | - | 6.32 | - | 2.22 |
| 2 | 60.0 | 42.1 | 0.5 | 20.006 | 19.417 | 15.356 | 11.732 | 30.89 | 89.38 | 2.12 | 8.49 | 1.19 | 2.94 |
| 3 | 60.0 | 36.3 | - | 20.013 | 19.592 | 15.180 | 11.981 | 26.70 | 85.82 | - | 14.18 | - | 2.10 |
| 4 | 60.0 | 37.2 | - | 20.072 | 19.473 | 15.082 | 11.984 | 25.85 | 85.13 | - | 14.87 | - | 2.98 |
| 5 | 60.0 | 37.7 | 0.1 | 20.020 | 19.767 | 15.187 | 10.943 | 38.78 | 84.34 | 1.12 | 14.54 | 0.27 | 1.26 |
| 6 | 60.0 | 22.1 | 0.2 | 20.088 | 19.049 | 15.009 | 11.326 | 32.50 | 61.22 | 9.70 | 29.08 | 0.91 | 5.17 |
| 7 | 60.2 | 44.5 | 0.3 | 20.013 | 19.709 | 15.065 | 11.642 | 29.40 | 96.73 | 3.26 | - | 0.67 | 1.52 |
| 8 | 60.2 | 34.3 | 0.2 | 20.023 | 19.052 | 15.091 | 11.694 | 29.05 | 79.22 | 1.16 | 19.62 | 0.58 | 4.85 |
| 9 | 60.0 | 35.0 | 0.1 | 20.065 | 19.229 | 15.072 | 11.431 | 31.85 | 79.55 | 3.40 | 17.05 | 0.29 | 4.17 |
| 10 | 60.2 | 39.2 | - | 20.010 | 19.417 | 15.220 | 11.530 | 32.00 | 86.73 | - | 13.27 | - | 2.96 |
| 11 | 60.6 | 24.8 | - | 20.059 | 18.786 | 15.162 | 10.730 | 41.33 | 67.39 | 5.44 | 27.17 | - | 6.35 |
| 12 | 60.1 | 37.2 | 3.3 | 20.024 | 18.774 | 15.100 | 11.483 | 31.50 | 84.16 | 2.26 | 13.58 | 8.9 | 6.24 |
| 13 | 60.9 | 38.0 | - | 20.027 | 19.507 | 15.128 | 12.200 | 24.00 | 81.20 | 2.78 | 16.02 | - | 2.60 |
| 14 | 61.9 | 51.1 | 0.1 | 20.029 | 19.724 | 15.047 | 13.400 | 12.29 | 90.60 | 0.53 | 8.87 | 0.2 | 1.52 |
| 15 | 60.0 | 15.0 | - | 20.016 | 18.088 | 15.012 | 10.200 | 47.18 | 38.66 | 9.79 | 51.55 | - | 9.63 |
| 16 | 60.5 | 22.7 | 0.1 | 20.010 | 18.392 | 15.149 | 11.033 | 37.31 | 51.59 | 9.77 | 38.64 | 0.44 | 8.09 |
| 17 | 60.0 | 4.7 | 0.1 | 20.058 | 16.434 | 15.147 | 11.014 | 37.53 | 11.90 | 24.81 | 63.29 | 2.13 | 18.07 |
| 18 | 60.1 | 50.0 | 1.1 | 20.027 | 19.323 | 15.179 | 12.328 | 23.13 | 94.70 | - | 5.30 | 2.20 | 3.52 |
| 19 | 60.3 | 46.5 | 0.2 | 20.033 | 19.652 | 15.065 | 11.764 | 28.06 | 90.64 | - | 9.36 | 0.43 | 2.04 |
| 20 | 60.0 | 37.3 | 1.3 | 20.036 | 19.311 | 15.074 | 11.100 | 35.80 | 80.91 | 1.09 | 18.00 | 3.49 | 3.62 |
| 21 | 60.4 | 28.4 | 1.2 | 10.028 | 9.315 | 15.111 | 9.835 | 53.65 | 70.65 | 4.98 | 24.37 | 4.23 | 7.11 |
| 22 | 60.2 | 33.6 | - | 10.021 | 9.719 | 15.126 | 11.400 | 32.68 | 77.42 | 4.61 | 17.97 | - | 3.01 |
| 23 | 60.1 | 9.1 | 0.2 | 10.015 | 8.783 | 15.044 | 9.835 | 52.96 | 32.04 | 8.80 | 59.16 | 2.20 | 12.30 |
| 24 | 60.5 | 8.1 | 0.1 | 20.021 | 17.404 | 15.093 | 10.853 | 39.07 | 21.95 | 21.68 | 56.37 | 1.23 | 13.07 |
| 25 | 60.1 | 7.3 | - | 15.024 | 12.890 | 15.063 | 10.700 | 40.78 | 18.67 | 24.30 | 57.03 | - | 2.76 |
| 26 | 60.4 | 45.4 | - | 20.010 | 19.566 | 15.084 | 12.877 | 17.14 | 86.97 | 0.96 | 12.07 | - | 2.22 |
| 27 | 60.2 | 39.7 | 1.4 | 15.092 | 14.676 | 15.067 | 12.460 | 20.92 | 83.58 | 4.21 | 12.21 | 3.53 | 2.76 |

| Sample | GRAIN SIZE ANALYSIS | | | ORGANIC CONTENT | | MOISTURE CONTENT | | RESULTS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wet sed. wt. | Dry sand wt. | >2mm. | Init | Burnt | Wet wt. | Dry wt. | % Moist | % Sand | % Silt/ Clay | % >2mm. | % Organic |
| 28 | 60.3 | 27.4 | 0.1 | 15.020 | 14.262 | 10.038 | 7.219 | 39.04 | 45.44 | 54.56 | 0.17 | 5.05 |
| 29 | 60.0 | 14.7 | - | 15.026 | 14.071 | 10.044 | 6.177 | 62.60 | 24.50 | 75.50 | - | 6.36 |
| 30 | 61.5 | 5.4 | 0.3 | 15.016 | 13.671 | 10.064 | 6.477 | 55.38 | 8.78 | 91.22 | 0.49 | 8.96 |
| 31 | 60.5 | 3.2 | (org.) 0.5 | 13.357 | 11.338 | 10.058 | 4.761 | 111.26 | 5.29 | 94.71 | 0.83 | 15.12 |
| 32 | 60.6 | 7.0 | - | 15.013 | 13.766 | 10.058 | 5.366 | 87.44 | 11.55 | 88.45 | - | 8.31 |
| 33 | 60.8 | 14.2 | 0.1 | 15.058 | 13.587 | 10.056 | 9.500 | 5.85 | 23.35 | 76.65 | 0.17 | 9.77 |
| 34 | 60.2 | 23.5 | 4.7 | 15.027 | 13.784 | 10.057 | 8.430 | 19.30 | 38.84 | 61.16 | 7.81 | 8.27 |
| 35 | 62.2 | 0.5 | - | 15.012 | 12.590 | 10.010 | 3.300 | 203.33 | 0.80 | 99.20 | - | 16.13 |
| 36 | 60.3 | 35.7 | (shells) 0.8 | 15.018 | 12.863 | 10.068 | 7.776 | 27.48 | 59.20 | 40.80 | 1.33 | 14.35 |
| 37 | 60.2 | 21.9 | - | 15.019 | 14.114 | 10.120 | 5.425 | 86.54 | 36.38 | 63.62 | - | 6.03 |
| 38 | 6[illegible].8 | 37.5 | - | 15.018 | 14.724 | 10.091 | 7.849 | 28.56 | 61.68 | 38.32 | - | 1.96 |
| 39 | 62.1 | 10.0 | 1.0 | 15.036 | 13.804 | 10.080 | 5.700 | 76.84 | 16.10 | 83.90 | 1.61 | 8.19 |
| 40 | 62.2 | 30.9 | 0.6 | 15.021 | 14.557 | 10.080 | 7.064 | 42.70 | 49.68 | 50.32 | 0.97 | 3.09 |
| 41 | 60.7 | 40.3 | - | 15.029 | 14.588 | 10.099 | 9.212 | 9.63 | 66.39 | 33.61 | - | 2.93 |
| 42 | 60.7 | 18.3 | - | 15.018 | 14.238 | 10.006 | 7.897 | 26.71 | 30.15 | 69.85 | - | 5.19 |
| 43 | 62.8 | 29.2 | 1.1 | 15.014 | 14.391 | 10.029 | 6.930 | 44.72 | 46.50 | 53.50 | 1.75 | 4.15 |
| A(0.75m) | 60.1 | 34.6 | (shell) 0.6 | 15.051 | 14.535 | 10.007 | 7.307 | 36.95 | 57.57 | 42.43 | 1.00 | 3.43 |
| E(0.2m) | 60.2 | 24.2 | 1.2 | 15.017 | 14.334 | 10.001 | 6.946 | 43.98 | 40.20 | 59.80 | 1.99 | 4.55 |
| F(0.6m) | 60.8 | 34.3 | 0.1 | 15.062 | 14.682 | 10.056 | 7.554 | 33.12 | 56.41 | 43.59 | 0.17 | 2.52 |
| G(0.8m) | 61.4 | 33.5 | 0.1 | 15.059 | 14.518 | 10.062 | 7.207 | 39.61 | 54.56 | 45.44 | 0.16 | 3.59 |
| H(0.5m) | 60.6 | 32.4 | (shell) 0.1 | 15.039 | 14.379 | 10.016 | 7.277 | 37.64 | 53.47 | 46.53 | 0.17 | 4.39 |
| I(0.5m) | 60.1 | 39.4 | - | 15.063 | 14.782 | 10.076 | 7.492 | 34.49 | 65.56 | 34.44 | - | 1.87 |
| J(1.0m) | 61.0 | 15.0 | - | 15.055 | 14.243 | 10.037 | 6.339 | 58.34 | 24.59 | 75.41 | - | 5.39 |
| K(1.0m) | 61.5 | 23.5 | (shell) 0.2 | 15.009 | 14.312 | 10.059 | 7.150 | 40.69 | 38.21 | 61.79 | 0.33 | 4.64 |
| L(0.2m) | 62.1 | 36.9 | - | 15.055 | 14.572 | 10.059 | 7.391 | 36.10 | 59.42 | 40.58 | - | 3.21 |
| M(1.0m) | 62.0 | 33.2 | (org.& rocks) 0.1 | 15.021 | 14.567 | 10.009 | 7.470 | 33.99 | 53.55 | 46.45 | 0.16 | 3.02 |

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